PRELIMINARY PLANNING ALTERNATIVES

FOR

SOLVING AGRICULTURAL DRAINAGE AND DRAINAGE-RELATED PROBLEMS IN THE SAN JOAQUIN VALLEY

August 1989

San Joaquin Valley Drainage Program

U.S. DEPARTMENT OF THE INTERIOR

Bureau of Reclamation
Fish and Wildlife Service
Geological Survey

CALIFORNIA RESOURCES AGENCY

Department of Fish and Game
Department of Water Resources

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PREFACE

Current agricultural drainage conditions on the west side of the San Joaquin Valley present two basic problems: (1) Salt buildup and waterlogging of irrigated lands due to a high ground-water table, which adversely affects crops and productivity, and (2) toxic or potentially toxic trace elements in the shallow ground water, which when drained and discharged to streams, ponds, or wetlands, can adversely affect fish and wildlife.

The severity of the toxics problem has been known only a relatively short time. It came into focus about 6 years ago with the discovery of migratory-bird deaths and deformities linked to high levels of selenium in agricultural drainage water at Kesterson Reservoir. Concentrations of drainage-water contaminants and rates of deformities higher than those found at Kesterson are now being found associated with evaporation ponds in the Tulare Basin, in the southern part of the valley.

Drainage problems affecting agriculture are almost as old as irrigated agriculture in the valley. As early as the 1890's, some cultivated lands were forced out of production because of salt and drainage problems. Despite the long history of drainage problems, efforts to solve them have been fragmented and remain uncompleted. Many people involved in drainage issues believe that a sustainable, long-term solution to the problems affecting agriculture will have to be accomplished in several phases. The first, and probably most critical, phase involves solving the problem of toxicants such as selenium.

Understanding of drainage conditions and problems in the valley has been greatly improved in the last few years, and critical evaluation of potential measures for solving those problems is required. Some 70 individual options that potentially could contribute to management of the problems have been identified by the Drainage Program, including measures that are currently being practiced as well as those that are as yet unproven and still under investigation. This report presents preliminary planning alternatives utilizing several of these options, all of which represent currently available technologies. The alternatives represent short-term or interim fixes to address problems expected to exist in the year 2000; in most cases, however, the measures and associated benefits would extend for many years. The Drainage Program is in the process of developing additional alternatives to meet both short- and long-term needs.

In 1987, the Drainage Program narrowed its focus on planning alternatives to measures that could be taken to address the agricultural drainage and related problems within the San Joaquin Valley itself. This decision reflected the need to control conditions and manage problems as close to their source as possible, and to help ensure that areas outside the valley are not adversely affected by the problems or measures to solve them.

We believe that the problem of toxicants such as selenium can be managed within the valley, particularly if over the next few years the cost of drainage-water treatment can be significantly reduced. It is equally clear, however, that because of its sheer magnitude the salt problem cannot be solved, over the long term, solely in the valley. At present, more than

3 million tons of salt accumulates each year in the shallow ground water, soils, and valley evaporation ponds. The long-term effect of not managing the salt-accumulation problem--to let present trends continue without implementation of a comprehensive management plan--will be to severely limit the uses and value of valley lands and ground water. As gains are made in managing drainage-water toxicants in the valley, the annual salt buildup should be reduced and opportunities will be greater for developing long-term solutions to the salt problem.

We look forward to your review of planning alternatives and to your participation in developing the best possible solutions to valley drainage and drainage-related problems.

Ed Imhoff

Edgar A. Imhoff, Manager
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EXECUTIVE SUMMARY

The lack of adequate drainage has long been recognized as a serious problem for irrigated agriculture in the western and southern San Joaquin Valley. For that reason, the Federal and State projects importing irrigation water to that area included plans for a master drainage canal leading to the Sacramento-San Joaquin Delta.

By 1975, 85 miles of the San Luis Drain, 120 miles of collector drains, and the first phase of Kesterson Regulating Reservoir were completed and began receiving subsurface drainage water from lands in the Federal service area.

In 1983, with the discovery of migratory-bird deaths and deformities linked to high selenium levels in agricultural drainage water at Kesterson Reservoir, it became clear that the valley's drainage problem involved not only agriculture, but also fish and wildlife resources, water quality, and possibly public health.

In mid-1984, five State and Federal agencies formed the San Joaquin Valley Drainage Program (SJVDP) to investigate drainage problems and identify possible solutions. In 1987, the SJVDP narrowed its focus on planning alternatives to measures that could be taken to address drainage and related problems within the valley itself. (Accordingly, the concept of a master drain leading out of the valley is not within the scope of this Program.)

This is a summary of the SJVDP's interim report on alternatives for solving valley drainage problems. The final report, due by October 1990, will include additional material based on public reviews and on research now nearing completion.

THE STUDY AREA

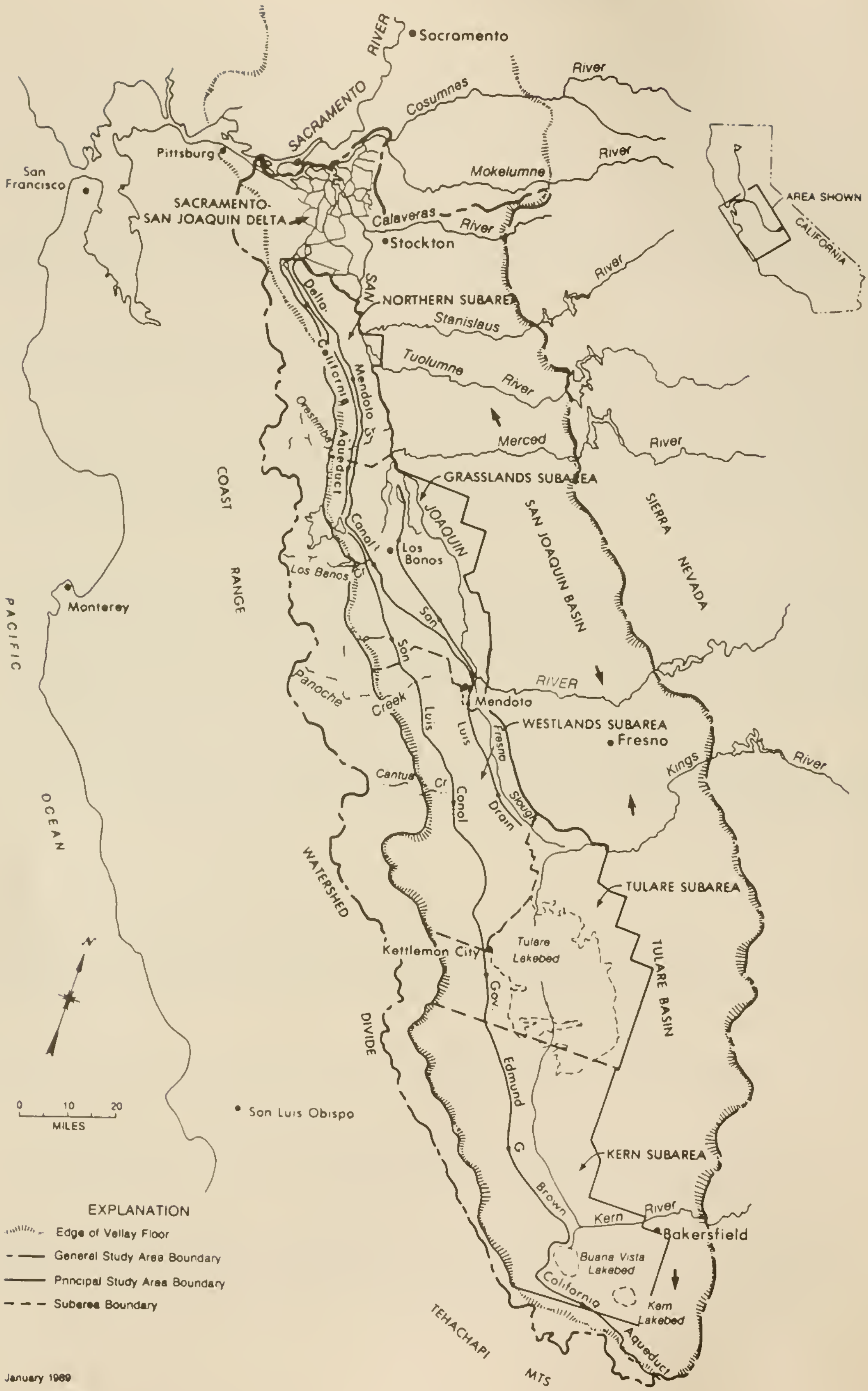
The SJVDP study area includes the entire valley but concentrates on the western half (the west side), where most of the drainage problems originate. The west side is divided into five subareas--Northern, Grasslands, Westlands, Tulare, and Kern. (See Figure 1.)

Certain geographical characteristics of the study area should be kept in mind:

- o The area is hot and dry, with average annual rainfall ranging from 5 inches in the south to 10 inches in the north. Irrigation is required for most agricultural crops.

- o The area contains two major drainage basins. To the north, the Northern and Grasslands Subareas and part of the Westlands Subarea drain naturally into the San Joaquin River (San Joaquin Basin). In

FIGURE 1
Program Study Areas



the south, the remainder of the Westlands Subarea and the Tulare and Kern Subareas drain into the Tulare Basin. The Tulare Basin is generally a closed basin, with outlet to the ocean through the San Joaquin River only in extremely wet years.

- Underlying much of the region is a clay layer (the "Corcoran Clay"), from 20 to 200 feet thick and several hundred feet below the surface. Ground water is found both below the Corcoran Clay and above it. Most irrigation wells draw from below it, and most salinized or contaminated water lies above it. The layer restricts downward water movement, but does not entirely stop it.

Historical Developments

Certain aspects of recent history help to put the drainage problem in context:

- By the 1950's, severe ground-water overdrafting for irrigation led to falling water tables along the west side.

- In the early 1950's, the first Central Valley Project (CVP) water reached the west side via the Federal Delta-Mendota Canal. This water replaced San Joaquin River water that had been used for irrigation on the west side but was now being diverted southward at Friant Dam.

- During the 1960's, new supplies of surface water were delivered through the CVP's San Luis Unit and the State Water Project (SWP) as far south as the Bakersfield area. This additional water was used for irrigation of some new land, but mainly replaced ground-water use. The surface water has replenished the ground-water aquifer and raised the water table. A long-term result, however, has been a slowly developing trend of waterlogging of irrigated lands as water tables have risen to near the land surface. Meanwhile, plans for a master drain to the Delta were not carried out, primarily because of concerns about adverse affects on water quality in the Delta and San Francisco Bay.

- The public law that authorized the San Luis Unit stated that construction would not be commenced until the Secretary of the Interior "has received satisfactory assurance from the State of California that it will make provision for a master drainage outlet and disposal channel for the San Joaquin Valley . . . or has made provision for constructing the San Luis interceptor drain to the Delta designed to meet the drainage requirements of the San Luis unit . . . " In the mid-1970's, the Bureau of Reclamation completed a partial drain for its San Luis Unit, with the drain ending in a series of evaporation ponds at Kesterson Reservoir. In 1983, selenium poisoning of waterbirds at Kesterson was discovered. In March 1985, the Secretary of the Interior ordered the cessation of subsurface drainage discharge to Kesterson Reservoir. By mid-May 1986, all feeder drains leading into the San Luis Drain and Kesterson had been plugged.

- Overall, the water and land development for agriculture has resulted in major losses of native habitats and associated damage to fish and wildlife populations. Subsurface drainage problems have added greatly to these problems.

West-Side Farming

Certain characteristics of irrigated agriculture in the area also help explain the drainage problem:

- More than 90 percent of the 2,470,000 acres classified suitable for irrigation in the study area are irrigated each year.

- About 135,000 acres have subsurface drainage systems.

- Most of the area is irrigated with surface (furrow or border) systems. About one-sixth is sprinkled, and a much smaller amount is drip-irrigated. Sprinklers usually apply water somewhat more efficiently than surface systems. However, there are considerable differences in efficiency among individual irrigation systems. There also are substantial differences in irrigation efficiency from one subarea to the next, and even within subareas.

- The practice of preirrigation (applying water to wet the root zone before the crop is planted) adds substantially to the amount of subsurface drainage water.

- Depending on hydrologic conditions, drainage from upslope lands can increase drainage problems on downslope lands.

- In the five subareas, average irrigation water costs to growers range from $16 to $50 per acre-foot. In some water districts, additional operating and pumping costs increase the total substantially.

Certain institutional issues have important implications for west-side irrigators. Among these are: (1) Water rights, including recent court decisions affecting application of the public-trust doctrine on traditional rights, (2) water and crop subsidies, (3) effects of the Reclamation Reform Act of 1982, and (4) the role of water districts. These issues are the focus of a study now being conducted by the SJVDP.

Environmental Resources

Wildlife--aquatic birds in particular--and fisheries are an important aspect of the valley's drainage problem. Most of the San Joaquin Valley's original lakes, wetlands, and riparian forests have been converted to other uses. Most of those that remain are in the Grassland Water District (in the Grasslands Subarea), where they have been managed to benefit waterfowl and other wetland species. Until recently, about two-thirds of the available water supply to these lands was agricultural drainage. However, drainage water can no longer be used for this purpose because of selenium and other potentially harmful contaminants. Maintenance of the existing wetlands, which are essential to the migratory bird populations of the Pacific Flyway, will require a new, nontoxic water supply.

Native fish in the San Joaquin Valley, such as the chinook salmon, have been largely lost as a result of dams, diversion of riverflows, and degraded water quality.

DRAINAGE AND DRAINAGE-RELATED PROBLEMS

Drainage problems in the valley consists of three separate but related conditions: (1) Shallow ground water, (2) salinity, and (3) selenium and other trace elements. All have implications for water quality, agriculture, fish and wildlife resources, and public health.

Shallow Ground Water

More than one-half of the study area has ground water within 20 feet of the land surface. This acreage has increased dramatically since the 1950's, as a result of rising water tables due to reduction of ground-water pumping after surface water was imported. (See Figure 2.) Problems for growers develop when the water table rises into the crop root zone, generally within 5 feet of the surface (10 feet for deep-rooted orchard crops).

In 1987, the study area contained about 847,000 acres with ground-water levels within 5 feet of the land surface part of the year--an increase from 537,000 acres only 10 years before. If current trends continue, by the year 2000 water tables will be within 5 feet or less of the land surface under 40 percent of all irrigated land in the study area.

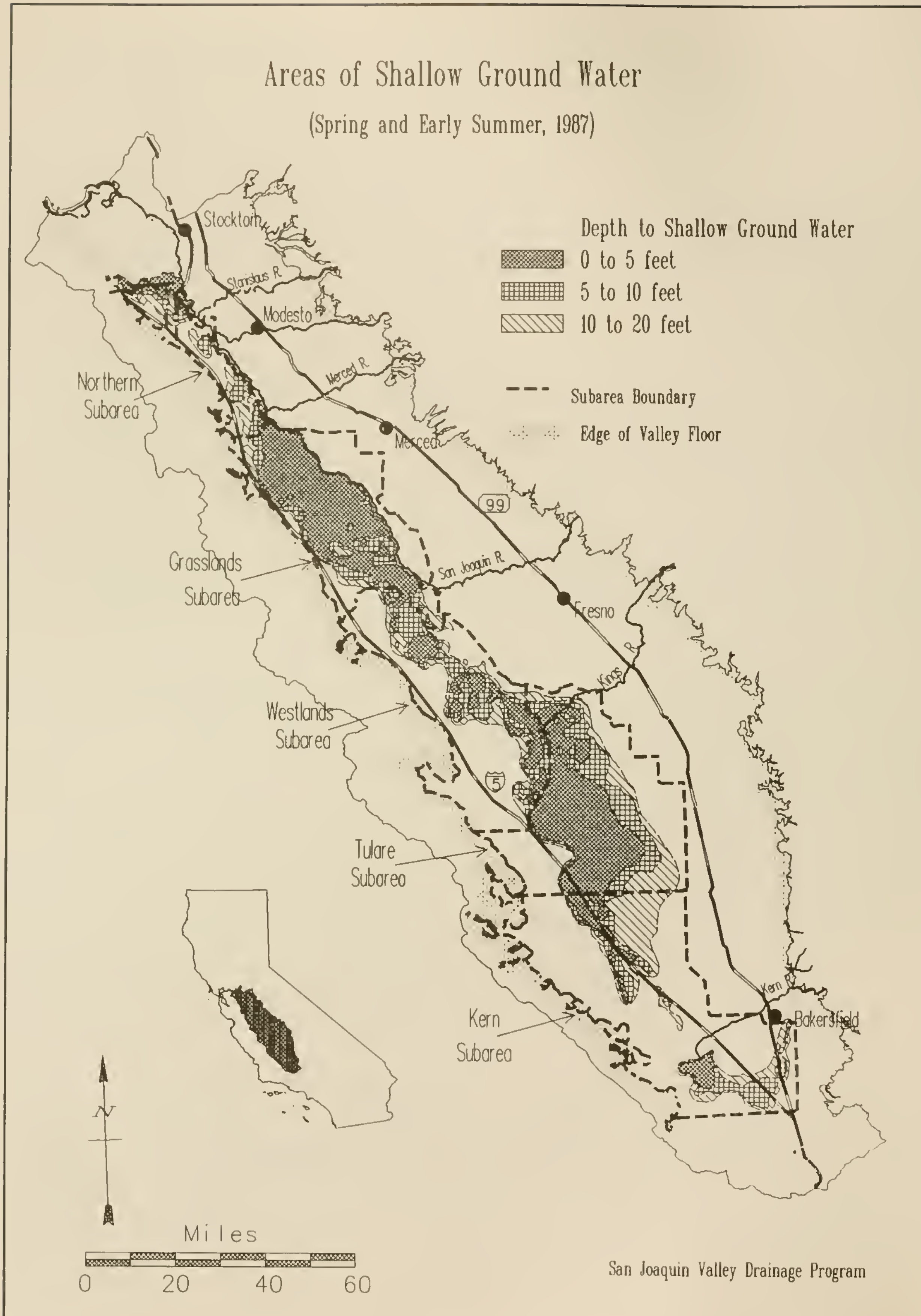
Generally, water tables rise when part of the irrigation water moves below the crop roots. This downward flow is called "deep percolation." Some deep percolation is necessary to leach salts from the root zone. This is the "leaching requirement." A recent study of irrigation performance in 83 west-side fields showed that:

- o Unless the entire field is underirrigated, some deep percolation beyond the leaching requirement is inevitable because irrigation water cannot be distributed with complete uniformity.

- o The average amount of water applied in the test fields was 2.5 acre-feet per acre per year, and average deep percolation was 0.8 acre-foot. Average irrigation efficiency was calculated at 66 percent. (A high level of irrigation efficiency without underirrigation would be about 80 percent. If that were achieved, deep percolation would be about 0.4 acre-foot per acre per year.)

Water tables continue to rise as long as more water enters a ground water system than leaves it. A computer model being used by the SJVDP shows that the two northern subareas (Northern and Grasslands) have reached hydrologic balance, so existing high water-table problems there are not likely to worsen. But if current trends continue, water tables in the Westlands, Tulare, and Kern Subareas will continue to rise until a hydrologic balance is achieved between recharge (through deep percolation) and discharge (primarily through evapotranspiration).

FIGURE 2



Areas of Shallow Ground Water
(Spring and Early Summer, 1987)
Depth to Shallow Ground Water
0 to 5 feet
5 to 10 feet
10 to 20 feet
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
Kern R.
Bakersfield
5
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
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Salts in Ground Water

The problem of high water tables is compounded by salinity. Salts are naturally present in valley soils, and also are imported with water from the Delta. Too much salinity damages crops and can be harmful to freshwater aquatic and wetland habitats. Salts can be leached below the crop root zone, but unless a high water-table field is drained, the salts concentrate in the shallow ground water and return to the root zone when the water table rises.

Vegetables, fruits, and nuts are sensitive to salt damage; grains, cotton, and sugar beets are more tolerant. Water with less than 2,000 parts per million (ppm) "total dissolved solids" (TDS) can be used to irrigate most salt-tolerant crops without reducing yields. With special management, crops have been irrigated with water containing as much as 5,000 ppm. Presently, shallow ground water contains higher salt concentrations under about 400,000 acres, largely in the Westlands, Tulare, and Kern Subareas. These waters can be used for irrigation only by blending with freshwater. (Figure 3 shows the salt content of the shallow ground water.)

Reaching a balance between salt entering and leaving a hydrologic system is crucial for sustaining long-term irrigated agriculture. The SJVDP's computer model of the west side shows a net increase of 3.3 million tons of salt each year in the semiconfined ground-water aquifer. Most of this is in the southern three subareas, where salts are steadily building up in ground water, soils, and evaporation ponds. Currently, the San Joaquin River removes some salts from the Grasslands and Northern Subareas, which helps to maintain salt balance in those subareas.

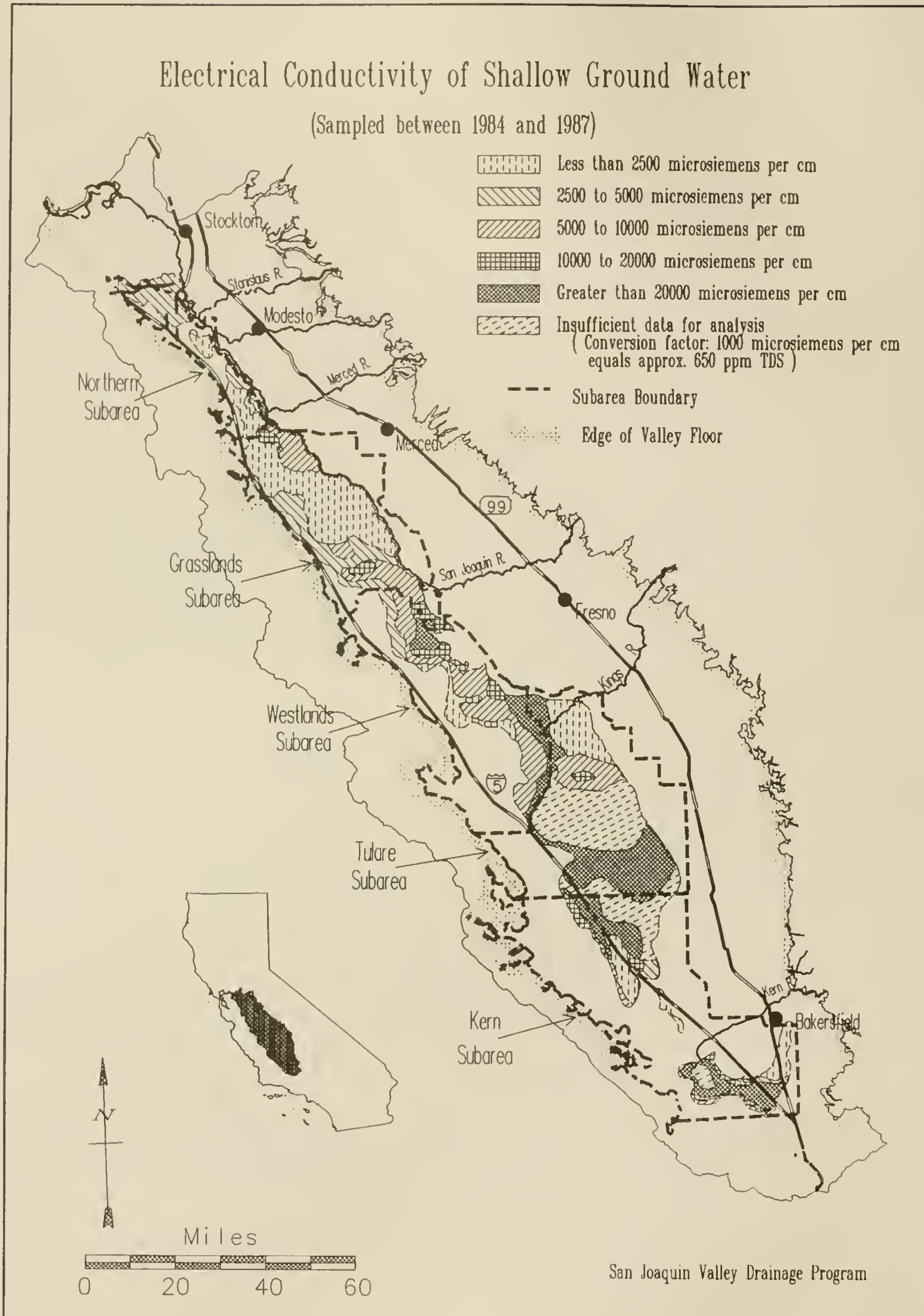
Trace Elements

Toxic and potentially toxic trace elements occur naturally in west-side soils and are leached into the shallow ground water during irrigation. Selenium is considered the chief threat because of its toxicity--to fish, wildlife, and potentially to humans--and because of its wide distribution. Other substances of primary concern are boron, molybdenum, and arsenic. The investigation of the drainage problem has included many other substances, some of which may eventually prove to be of primary concern.

The highest remaining concentrations of selenium in the soil are in more recently irrigated areas lying between alluvial fans (stream-deposited materials from the Coast Ranges) in the Westlands and Kern Subareas. Elsewhere along the west side, decades of irrigation and deep percolation have transferred much of the soluble soil selenium into shallow ground water--where it is distributed along the lower parts of alluvial fans. (See Figure 4.)

Selenium concentrations tend to be higher in more saline ground water. Where the water table is less than 5 feet below the land surface, selenium, boron, and salts can become increasingly concentrated as crops and evaporation remove the ground water but leave behind most of the minerals.

FIGURE 3



Electrical Conductivity of Shallow Ground Water
(Sampled between 1984 and 1987)
Less than 2500 microsiemens per cm
2500 to 5000 microsiemens per cm
5000 to 10000 microsiemens per cm
10000 to 20000 microsiemens per cm
Greater than 20000 microsiemens per cm
Insufficient data for analysis
(Conversion factor: 1000 microsiemens per cm equals approx. 650 ppm TDS)
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
5
Kern R.
Bakersfield
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
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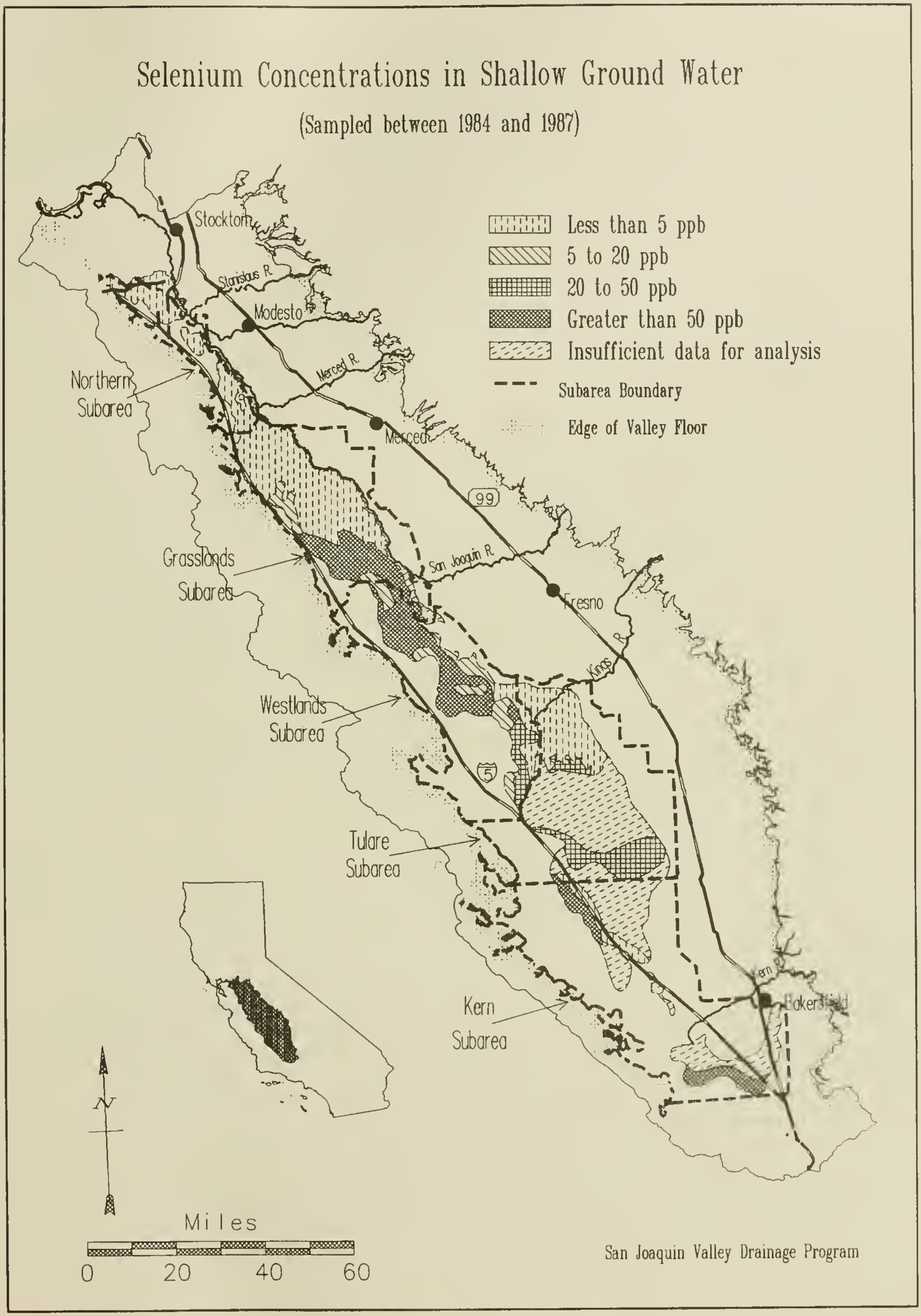
FIGURE 4


Selenium Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Less than 5 ppb
5 to 20 ppb
20 to 50 ppb
Greater than 50 ppb
Insufficient data for analysis
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
5
Kern R.
Bakersfield
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
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The SJVDP also has studied selenium in the San Joaquin River. During the irrigation season, agricultural drainage water provides almost the entire flow of the middle portion of the river. Most selenium entering the river is dissolved in drainage water that is transported primarily through Salt and Mud Sloughs. Water in the San Joaquin River downstream from those sloughs exceeds State-proposed selenium water-quality objectives for protection of aquatic life (5 parts per billion) more than 40 percent of the time.

The SJVDP has surveyed other trace elements in soils and ground water, finding:

- Elevated concentrations of boron in parts of all subareas except the Northern Subarea.

- Elevated concentrations of arsenic and molybdenum in old lakebeds in the Tulare and Kern Subareas.

Trace elements, including selenium, also are found in evaporation ponds--sometimes in very high concentrations. There are about 7,500 acres of evaporation ponds in the San Joaquin Valley, primarily in the Tulare and Kern Subareas. No other method for disposing of very saline drainage is currently available in those areas.

Evaporation ponds attract large numbers of aquatic birds and provide wintering and nesting habitats. Adverse effects of selenium on embryos and young birds have been documented at several ponds. Evaporation ponds are the greatest threat to aquatic birds of any drainage-related facilities in the valley.

Humans are most likely to contact agricultural drainage-water contaminants through a variety of indirect means (for example, consumption of contaminated fish or wildlife, wild or cultivated plants, or livestock; consumption of or skin exposure to contaminated soils or sediments; and inhalation of contaminated air).

Studies throughout the western San Joaquin Valley have shown that certain types of fish and wildlife have accumulated sufficient levels of selenium that advisories have been issued by the State to restrict consumption of these plants and animals. Preliminary research on a small number of samples from the area has indicated that cultivated plants and domestic livestock do not contain excessive selenium concentrations; however, other substances of concern have not, as yet, been measured. Early health surveys of population groups considered at risk for overexposure to selenium (Kesterson Reservoir workers and a small foraging population) have not shown evidence of selenium toxicity; however, other groups that may be at risk (for example, hunters and fishermen, or subsistence gardeners in contaminated areas) have not been evaluated. The degree to which the public adheres to health advisories is not known. Qualitative risk assessments for public exposure to other drainage-water contaminants currently are under preparation. In the interim, a number of actions have been recommended to reduce potential public health risks.

POSSIBLE OPTIONS

The following list of drainage management options is summarized from Chapter 3 of the report. Some of these options already are in use, some are in the experimental stage, and some are untested. Some are technological in nature, some would offer economic incentives, some are management-oriented, and some are institutional.

No single option is likely to solve a major part of the valley's drainage problems. What will solve the drainage problem, it is hoped, are certain combinations of options that are proposed as alternative plans for each subarea. One such set of alternative plans, utilizing available technologies, is described in a following section of this summary.

There are many possible in-valley approaches to managing the valley's drainage problems. Most of them are workable only in combination with others. No single one applies to every problem site.

The options fall into seven categories:

- Source control to reduce drainage from individual farms.
- Management of shallow water tables by pumping.
- Drainage-water treatment.
- Drainage-water reuse.
- Drainage-water disposal in the valley.
- Fish and wildlife measures.
- Institutional changes.

Source Control

There are four approaches to drainage source control on the farm: (1) Water conservation, (2) drainage management, (3) crop management, and (4) alternate land use.

Water conservation options include:

- Use better irrigation methods such as shorter furrow lengths, recycled tailwater, and sprinkler, drip, or improved furrow systems.
- Improve scheduling of irrigation, making use of available data on root-zone storage capacity and crop water use rates.
- Improve irrigation management.
- Deliver irrigation water more promptly on demand by providing more conveyance capacity where necessary, more conjunctive use of surface and ground water, and more coordination of water delivery systems.

- Intercept or reduce seepage from canals, ditches, and natural channels.

- Adapt tillage practices to distribute water more uniformly and reduce deep percolation.

Drainage management options include:

- Separate surface and subsurface drainage, so waters of different quality can be managed more efficiently.

- Recycle tailwater from surface irrigation systems.

- Regulate water tables by controlling tile-drain flows in order to make more shallow ground water available for crop use.

- Space tile drains closer together in order to intercept only the better quality ground water that lies closer to the surface.

Crop management options include:

- Grow crops that tolerate salts, high water table, or drought, in order to reduce the need for drainage.

- In areas with highly contaminated soils or ground water, grow nonirrigated crops with minimal water requirements.

- Grow crops that accumulate or volatilize selenium.

Alternate land use options include:

- Cease irrigating "hot spots" of selenium by purchasing the land or by using economic incentives. Another possibility is to reclassify land within the CVP as "nonirrigable."

- Convert irrigated lands to upland wildlife habitat.

- Convert irrigated lands to wetland habitat.

Ground-Water Management

In addition to individual farm source control, ground-water management could be implemented by districts or regions. This would mean increasing the pumping of ground water over substantial areas in order to lower the shallow water table. These options include:

- Pumping more water from below the Corcoran Clay. Increased pumping from below the clay could alleviate, indirectly, the water-table problem near the surface by causing the shallow ground water to lower as water would move toward well-column inlets (hundreds of feet below the surface). A gradual deterioration of water quality in the deep aquifer and land subsidence would likely accompany large-scale pumping.

- Pumping from the Sierran sands along the eastern side of the study area. Pumping from depths of 30 to 250 feet below the land surface could also lower water tables and provide a low-selenium, although somewhat saline, supplemental water supply.

- Pumping from Coast Range alluvium along the west side of the study area. An SJVDP model suggests that regional-scale pumping at 200 to 300 feet could lower water tables as effectively as tile drains. Water presently below 150 feet is moderately saline, but is likely to contain little selenium. However, with long-term pumping, selenium-contaminated shallow ground water would likely move downward.

- Pumping shallow water. In the Northern Subarea, shallow, saline ground water might be pumped into the San Joaquin River during high flows, leaving more room in the aquifer for deep percolation during the irrigation season.

Reliable site-specific forecasts of the probable effects of ground-water management options will depend on results of additional investigations.

Drainage-Water Treatment

Various studies have been and are being conducted to identify affordable methods of removing trace elements (primarily selenium) from drainage water. Most of these options are still in the laboratory test stage. A few are somewhat more advanced, but additional work with pilot prototype plants is needed to test performance and to estimate costs.

There are no immediate prospects for an economically feasible way to remove selenium, or boron and salts, from drainage water, but such a process is badly needed--if only to deal with concentrated selenium residues in evaporation ponds.

Potential treatment processes include:

- Five biological methods: anaerobic-bacterial, facultative-bacterial, microalgal-bacterial, microbial volatilization in evaporation ponds, and microbial volatilization from soils and sediments.

- Six physical-chemical methods: geochemical immobilization, adsorption using iron filings, adsorption using iron oxides, ion exchange, reverse osmosis, and cogeneration to produce electricity plus heat for desalinization.

Drainage-Water Reuse

Where there are no disposal outlets, saline drainage water is commonly mixed with freshwater for reuse in irrigation. This practice can result in the buildup of salt in soil and shallow ground water and eventually damage crops. One suggested strategy is to use freshwater to establish young plants, and then to irrigate the crop with drainage water--making sure that the root zone is well drained.

Subsurface drainage water containing salinity (TDS) of up to 3,000 ppm has been used to grow salt-tolerant commercial crops. Eucalyptus trees for firewood or wood pulp and saltbush for forage can be irrigated with even more saline water--if salts are leached from the root zone.

Plantings of eucalyptus and saltbush also could benefit wildlife, assuming (from preliminary studies) that the buildup of toxic trace elements does not cause problems.

Other potential options for reuse of drainage water:

- Use it to cool fossil-fueled powerplants. Costly water treatment would be required. Also, there are no plans to locate new powerplants in the valley, and existing plants have cooling water supplies.

- Use it in solar ponds to produce electrical energy. This process has been demonstrated on a small scale, but cannot compete economically with conventional powerplants unless fuel oil prices again rise to about $30 per barrel.

- Recover salts from evaporation ponds for industrial use. Much more refining might be required. Even an unprofitable operation, however, might be justified as part of a drainage disposal system.

- Use drainage water in aquaculture. The possibility of trace-element concentration would have to be considered in determining the marketability of any organisms grown in drainage water.

Drainage-Water Disposal

Several options for drainage disposal depend on using the San Joaquin River. Drainage from the Northern and Grasslands Subareas currently goes into the river. In the future, the availability of the river will depend on the salinity water-quality objectives set for the river. It is estimated that most of the Northern Subarea and almost half of the Grasslands Subarea could be drained directly into the river and still meet the objectives.

Other potential options involving the San Joaquin River:

- Use freshwater to dilute drainage water going into the river (particularly in the Northern Subarea). The cost would be prohibitive if selenium concentrations are above 50 ppb. (Under current law, dilution is not a beneficial use of freshwater.)

- Clean and use part of the San Luis Drain north of the Mendota Pool to convey freshwater to the Grasslands area. The northern part of the drain would be used to convey drainage water around the Grasslands area and through sloughs to the river.

Other options for drainage disposal are:

- Evaporate drainage water in ponds, currently a common practice in the southern valley. Ponds are regulated by the State through the issuing of waste discharge permits, which now must be accompanied by an agreement between the owner or operator and the California Department of Fish and Game that wildlife will be protected. Starting in 1989, regulatory agencies will work toward developing mitigation actions to offset unavoidable effects of pond operation. It is likely that the problems of selenium toxicity will cause the costs and operation of most ponds to rise sharply as regulations require, in effect, that ponds be bird-free or bird-safe.

- Clean and use the San Luis Drain south of the Mendota Pool to convey drainage water for treatment and disposal within the Westlands Subarea.

- Transport drainage water to the western edge of the valley and use it to irrigate eucalyptus trees and/or saltbush over a present ground-water table depression.

- Inject drainage water into saline ground water below the freshwater zone, 3,000 to 3,500 feet down.

- Inject drainage water into very deep (7,000 feet or more) saline geological formations. A deep-well injection testing program is being conducted near Mendota.

- Transport some drainage water (30,000 to 60,000 acre-feet yearly) to the east side of the valley. Irrigation water soil-infiltration problems on the east side of the valley are caused by water supplies low in salt and relatively high in sodium; also, forage crops there are generally selenium-deficient. The overall chemical effects of imported drainage water would have to be considered.

Fish and Wildlife Measures

Fish and wildlife objectives include: (1) Protection of populations, (2) restoration of habitat, (3) provision of substitute water supplies, and (4) improvement of the resources.

Options for protection of fish and wildlife include:

- More aggressive implementation/enforcement of amendments to existing laws, or passage of new laws addressing: planning, environmental assessment, and mitigation.

- Regulation of take of fish and wildlife.

- Regulation of land and water uses.

- Regulation of water quality.

Options for restoration of drainage-contaminated fish and wildlife habitats include:

- o Flooding and flushing with freshwater.
- o Soil and vegetation management.
- o Cultivation and harvesting of selenium-accumulating plants.
- o Microbial volatilization.
- o Geochemical immobilization.
- o Sequential implementation of decontamination and restoration.

Options for providing wildlife areas with nontoxic freshwater supplies to substitute for drainage water previously used include:

- o Reuse of drainage water.
- o Reallocation of freshwater supplies.
- o Altered sequence of water delivery.
- o Modifications to existing or proposed water-storage projects and delivery systems.
- o Wetlands water storage.

Options for improving the status of the valley's fish and wildlife resources beyond protection, restoration, and substitute water-supply levels include:

- o Agroforestry.
- o Management, development, reclamation, and acquisition of fish and wildlife habitats and associated public-use facilities.
- o Uncontaminated evaporation ponds/wetlands.

Institutional Changes

The SJVDP study includes a number of possible changes in laws, policies, and practices in order to help solve drainage problems and to protect fish and wildlife resources. Many of these options provide economic and other incentives for growers to conserve irrigation water and/or reduce the production of agricultural drainage water. The institutions involved include local, regional, State, and Federal water agencies and others.

These options are:

- o Raise the price of water through water supply contracts. This would require renegotiation of contracts, and a fundamental shift in Federal and State policies. Preliminary analyses indicate that significant price increases would be needed to motivate growers to change irrigation methods and management.

- Charge higher water rates at the district level, with excess funds rebated or applied to drainage management programs.

- Modify or eliminate irrigation subsidies, including those on Federal and, possibly, State water supplies.

- Allow water districts (and growers) to pay only for water actually used and to receive credit for unused water.

- Use tiered water pricing. This means that per-unit prices increase as subsequent "blocks" of water are used by a grower during a season. Tiered pricing of Federal and State project water would require changes in Federal and State law and/or policy.

- Make it easier to: (1) Trade water, which would increase the value of transfers and thereby encourage conservation, or (2) market water, which, besides encouraging conservation, might eliminate irrigation on lands with severe drainage problems.

- Rebate taxes based on total water management efficiency measured by reduction in subsurface drainage water produced.

- Provide income tax credits for investments in water conservation.

- Authorize use of Federal and State water to dilute agricultural drainage water so the water could meet discharge standards of, for example, the San Joaquin River.

- Impose drainage-effluent fees on growers and/or water districts, in proportion to the amount and quality of drainage water.

- Limit the amount of very poor-quality drainage water discharged from farms, districts, or regions.

- Allow growers to trade permits for off-farm discharge of limited amounts of drainage-water constituents (e.g., selenium, boron, or salts).

- Form a regional drainage district to address drainage and drainage-related problems more effectively and economically. Members could be either water districts or individual growers.

- Increase subsidies on Federal and State project water going to private and public wetlands, in order to improve wildlife habitats.

- Authorize CVP and SWP water for environmental and other uses before agriculture.

- Reallocate water from agriculture to fish and wildlife uses. This would probably require agency agreements and perhaps legislative action. One way to save water for reallocation to fish and wildlife would be to reduce irrigation demand through increased conservation or land retirement. Another would be to redefine "beneficial use" of water to exclude: (1) Production of highly contaminated drainage, or (2) irrigation in excess of crop water use plus leaching.

- Reauthorize the Federal and State Water Projects to give equal consideration to water needs of fish and wildlife.

ALTERNATIVE PLANS

Certain options from the preceding list have been combined into preliminary alternative plans that emphasize what might be done between now and the year 2000 to address the drainage problem using "available technology." An alternative plan has been developed for each subarea, tailored to water-quality zones. (Within each subarea, drainage problem land is divided into several water-quality zones.)

Additional alternative plans emphasizing other themes--such as ground-water management, drainage-water treatment, and land retirement--are being formulated. The SJVDP's final report will present a number of possible plans, including recommendations for action. These plans will reflect information obtained from upcoming public meetings and from research and special studies on: (1) Geohydrology, (2) quality of ground water in the Tulare and Kern Subareas, (3) deep-well injection for drainage disposal, (4) treatment of drainage water to remove selenium and other toxics, (5) agricultural economics, and (6) advantages and disadvantages of various possible institutional changes.

The alternative plans presented in this report include only options of currently available technology. These preliminary plans share a common strategy:

- First, through water conservation, substantially reduce the amount of drainage water produced through irrigation.

- Then, use the drainage water collected to grow salt-tolerant plants, which will evapotranspire much of the water and concentrate the dissolved minerals.

- Finally, store the remaining volume of saline water underground or in small evaporation ponds (to be managed as bird-safe or bird-free disposal sites).

- Also, in some subareas, some drainage water would go into the San Joaquin River, to the extent that the river can assimilate it while meeting water-quality objectives.

- Irrigation water made available through on-farm water conservation, pumping of ground water, and growing of salt-tolerant crops would be allocated to wetlands and rivers, to increase protection of fish and wildlife, to help decontaminate and restore habitat, and to provide substitute water supplies.

The No-Action Scenario

Before discussing alternative plans, it is appropriate to ask: What if there were no plans? What if no coordinated, comprehensive public and private action is taken to solve the valley's drainage problem?

Assuming that existing trends generally continue in the agricultural economy, in environmental protection activities, in governmental spending, and in water development and use, and also assuming no drainage outlet from the valley, then such a future without a coordinated, comprehensive plan to deal with drainage water very likely would result in:

- Even more acreage with high water tables and even more saline ground water, both conditions leading to substantial loss of farmland.
- Increasing public pressure for environmental protection, resulting in existing valley wetlands and wildlife areas being preserved and protected, but no new areas or water supplies being developed for these needs.
- Uncoordinated actions by various individuals and groups, leading to litigation not only between agricultural and environmental interests, but among similar user and interest groups.
- Piecemeal legislation and institutional changes, leading to fewer choices and greater costs for almost everybody involved.

Preliminary Alternative Plans

The SJVDP's first set of alternative plans is designed to use available technology to eliminate or dispose of "problem water." Problem water is ground water within 5 feet of the surface of irrigated lands during at least part of the year, and which generally has chemical characteristics that adversely affect agriculture--and if drained, fish and wildlife, public health, or attainment of State water-quality objectives. In developing these plans, the first step was to divide each subarea into zones based on shallow ground-water quality, and then forecast the yearly volume of problem water expected in that zone by the year 2000.

The next step was to outline a procedure to reduce the production of drainage water as much as possible (source control) and then concentrate the remaining problem water so that only a small amount would have to be stored or disposed of. To do this, it is assumed that:

- Growers would improve irrigation efficiency to reduce deep percolation, using better irrigation management and scheduling and such technologies as shorter furrow lengths and tailwater return systems. These on-farm techniques should reduce drainage-water production by 40 to 50 percent in most zones.
- In certain areas, some drainage water would go into the San Joaquin River (where permitted by State water-quality objectives).
- Some of the remaining problem water could be used to irrigate salt-tolerant crops such as cotton and grain. Drainage from those crops would be applied to plantings of eucalyptus trees; in turn, drainage from the eucalyptus trees would be partially consumed by plantings of saltbush.

- The remaining highly concentrated drainage water would be disposed of in two ways: (1) In evaporation ponds made bird-safe or bird-free, or (2) by pumping deep ground water from below the saltbush, thereby lowering the water table in that locality to permit storage of saline drainage water in the shallow aquifer.

Finally, a preliminary estimate was made of costs for the alternative plan. These costs will be compared with the costs of other alternatives now being developed. Detailed economic analyses of both direct and indirect benefits, costs, and impacts will be made.

The ways in which options are combined and the extent to which they are used vary by subarea and by water-quality zone. Each subarea alternative plan reflects the water-quality, environmental, and agricultural conditions in that subarea.

Overall Impacts

How much problem water would be dealt with in each step of the process? Here are overall estimates for the Grasslands, Westlands, Tulare, and Kern Subareas, where the amount of problem water in the year 2000 is forecast to total 307,500 acre-feet yearly from 409,000 acres of land.

Acre-feet of problem water reduced yearly by improved irrigation management	128,800
Discharged to the San Joaquin River	35,000
Removed by reuse on eucalyptus trees and saltbush	120,200
Stored in ground water	11,400
Stored in evaporation ponds	12,100
TOTAL	307,500

What effects would the proposed plans have on land and water use? How much would they cost? Here are total estimates for the four subareas:

Cropland converted to eucalyptus groves and saltbush fields	28,200 acres
Irrigation water saved, mostly by reduced deep percolation (this alternative includes hypothetical allocation of this water for fish and wildlife purposes)	200,000 acre-feet
Total costs per year	$29.4 million
Yearly cost per acre-foot of problem water	$96
Yearly cost per acre of land with drainage	$72

What environmental effects--on the San Joaquin River, and on fish and wildlife, for example--could be expected? What about public health?

All drainage water from the Northern Subarea and about 60 percent of the drainage water from the Grasslands Subarea, because of its relatively good quality, could be assimilated safely by the river. Discharge of the remaining Grasslands drainage water would not be acceptable, because the selenium-assimilating capacity of the river would be exceeded.

Elsewhere on the west side, storage of highly concentrated drainage--even in relatively small amounts--would require special precautions. Aquatic birds would have to be kept out of most evaporation ponds; adjacent wetland areas to attract the birds might be required. Storage of concentrated drainage in shallow aquifers would, over time, degrade the ground-water resource. Wildlife in eucalyptus groves and saltbush fields would have to be monitored for harmful effects.

Public health concerns involve hunters, fishermen, and foragers in high-selenium locations. Actions to inform these users of potential public health problems and preclude their access to toxic evaporation ponds are a part of this alternative.

Impacts on Subareas

Throughout the study area, the alternative plans developed so far for water-quality zones reflect local conditions. Here, briefly summarized from the individual zone plans, are the preliminary alternative plans for the five subareas. (Drainage volume reductions for the subareas are also summarized in Table 1 [page 24]. Table 2 [page 25] summarizes major direct effects of the alternatives by water-quality zone.)

Northern Subarea. Because drainage problems in this far northern end of the study area are relatively minor, no alternative plan is presented under the theme of available technologies.

Grasslands Subarea. Annual volume of problem water in the year 2000: 86,000 acre-feet from 116,000 tile-drained acres.

Planned procedure for reducing the volume of problem water:

- On-farm source control: 27,200 acre-feet.
- In areas free of selenium, all subsurface drainage water would be discharged into the San Joaquin River: 22,000 acre-feet.
- Discharge of drainage with selenium to San Joaquin River (within the river's selenium-assimilative capacity): 13,000 acre-feet.
- Drainage-water reuse on eucalyptus and saltbush: 21,900 acre-feet.

- Pumping from below saltbush plantings to create storage space in the aquifer for drainage of water from the saltbush: 1,700 acre-feet.

- Evaporation ponds: 200 acre-feet.

- Estimated cost: $63/acre-foot of drainage water, or $47/acre of contributing land.

Proposed actions to protect and/or restore public health and fish and wildlife:

- Public warnings about hunting, fishing, and food-gathering in areas where selenium concentrations are high.

- Nontoxic freshwater supplies (conserved from agricultural irrigation) for existing wetlands and wildlife areas (129,000 acre-feet/year) and instream flows in the Merced River (20,000 acre-feet/year).

Westlands Subarea. Annual volume of problem water in the year 2000: 84,000 acre-feet from 108,000 tile-drained acres.

Planned procedure for dealing with problem water:

- On-farm source control: 37,900 acre-feet.

- Drainage-water reuse on eucalyptus and saltbush: 40,400 acre-feet.

- Pumping from below saltbush plantings to create storage space in the aquifer for drainage of water from the saltbush: 5,300 acre-feet.

- Evaporation ponds: 400 acre-feet.

- Estimated cost: $103/acre-foot of drainage water, or $77/acre of contributing land.

Proposed actions to protect and/or restore public health and fish and wildlife:

- Public warnings about waterfowl hunting in high-selenium localities.

- Hazing or other methods to reduce harm to aquatic birds at toxic evaporation ponds.

Tulare Subarea. Annual volume of problem water in the year 2000: 92,000 acre-feet from 126,000 tile-drained acres.

Planned procedure for dealing with problem water:

- On-farm source control: 42,700 acre-feet.

- Drainage-water reuse on eucalyptus and saltbush: 41,100 acre-feet.

- Pumping from below saltbush plantings to create storage space in the aquifer for drainage of water from the saltbush: 300 acre-feet.

- Evaporation ponds: 7,900 acre-feet.

- Estimated cost: $115/acre-foot of drainage water, or $86/acre of contributing land.

Proposed actions to protect and/or restore public health and fish and wildlife:

- Public warnings about waterfowl hunting at evaporation ponds.

- Nontoxic freshwater supplies (conserved from agricultural irrigation) for existing wetlands and wildlife areas (9,700 acre-feet/year).

- Hazing or other methods to reduce harm to aquatic birds at toxic evaporation ponds.

Kern Subarea. Annual volume of problem water in the year 2000: 45,500 acre-feet from 60,000 tile-drained acres.

Planned procedure for dealing with problem water:

- On-farm source control: 21,000 acre-feet.

- Drainage-water reuse on eucalyptus and saltbush: 16,800 acre-feet.

- Pumping from below saltbush plantings to create storage space in the aquifer for drainage of water from the saltbush: 4,100 acre-feet.

- Evaporation ponds: 3,600 acre-feet. (All but 200 acre-feet would go to already existing ponds.)

- Estimated cost: $105/acre-foot of drainage water, or $79/acre of contributing land.

Proposed actions to protect and/or restore public health and fish and wildlife:

- Public warnings about waterfowl hunting near evaporation ponds.

- Nontoxic freshwater supplies (conserved from agricultural irrigation) for existing wetlands and wildlife areas (38,000 acre-feet/year).

- Hazing or other methods to reduce harm to aquatic birds at toxic evaporation ponds.

TABLE 1

SUMMARY OF DRAINAGE VOLUME REDUCTION
AVAILABLE TECHNOLOGIES ALTERNATIVE
(acre-feet)

(Estimated volume of Problem Water to be managed by Year 2000 = 307,500 acre-feet)

SUBAREA	REDUCTION OR DISPOSAL METHOD					TOTAL
	IRRIGATION IMPROVE-MENTS	DISCHARGE TO SAN JOAQUIN RIVER	EUCALYPTUS AND SALTBUSH PROPAGATION (REUSE)	GROUND-WATER STORAGE	EVAP POND DISPOSAL	
GRASSLANDS	27,200	35,000	21,900	1,700	200	86,000
WESTLANDS	37,900	0	40,400	5,300	400	84,000
TULARE	42,700	0	41,100	300	7,900	92,000
KERN	21,000	0	16,800	4,100	3,600	45,500
TOTAL	128,800	35,000	120,200 (a)	11,400	12,100	307,500

(a) Includes about 20,000 acre-ft reduction in deep percolation, due to replacement of conventional crops with special crops such as eucalyptus trees (assumes no freshwater supply).

TABLE 2

MAJOR DIRECT EFFECTS
AVAILABLE TECHNOLOGIES ALTERNATIVE

SUBAREA	WATER QUALITY ZONE	IRRIGATED LAND AREA REDUCTION (acres)	AGRICULTURAL WATER REQUIREMENT REDUCTION (acre-feet/year)	TOTAL ANNUAL COST ($1,000)	SUPPLEMENTAL FISH & WILDLIFE WATER SUPPLIES (acre-feet/year)
GRASSLANDS	A	3,600	38,400	4,642	
	B	800	5,500	769	
	C	0	0	0	
	Subtotal	4,400	43,900	5,411	149,000 (a)
WESTLANDS	A	2,300	17,700	2,425	
	B	1,900	14,800	1,500	
	C	3,600	27,200	3,760	
	D	800	6,700	955	
	Subtotal	8,600	66,400	8,640	0
TULARE	B	3,100	16,700	2,879	
	C	300	3,000	390	
	D	700	4,900	717	
	E	2,050	13,900	2,342	
	F	3,800	24,400	4,270	
	Subtotal	9,950	62,900	10,598	9,700 (b)
KERN	A	2,100	14,300	2,085	
	B	200	1,600	154	
	C	350	2,400	359	
	D	2,600	21,600	2,176	
	Subtotal	5,250	39,900	4,774	38,000 (b)
TOTAL		28,200	213,100 (c)	29,423	196,700

(a) Includes 20,000 acre-feet of anadromous fish flows down the Merced River and 129,000 acre-feet of substitute wetland-wildlife habitat water supplies.
(b) Alternative habitat water supply associated with hazing of evaporation ponds.
(c) Reduction includes 128,800 acre-feet due to improved irrigation and drainage management practices, 72,900 acre-feet due to reduction in irrigated agricultural lands (used to grow eucalyptus trees and saltbush), and 11,400 acre-feet due to increased ground-water pumping to control shallow water depth.

ACTIVITIES AND SCHEDULE FOR PROGRAM COMPLETION

A range of alternatives for the planning subareas are being formulated and evaluated. Opportunities are being provided for the general public, special-interest groups, and governmental agencies to play important roles in this formulation and evaluation process. Comments are being solicited and utilized throughout the planning process, which will culminate in the recommendation of subarea plans and/or a comprehensive plan for the west side of the valley.

The SJVDP also is completing technical studies and other work that fall into two primary areas: (1) Special studies to provide specific information critical to plan formulation and evaluation, and (2) improving the analytic tools used in evaluating options and planning alternatives. Studies are being completed in 1989 and early 1990 on specific aspects of:

- Geohydrology.
- Public health.
- Fish and wildlife resources.
- Treatment technology.
- Institutional studies.
- Social analysis.

Work to improve evaluative tools centers around the SJVDP's computerized Westside Agricultural Drainage Economics model. The model covers the principal study area and defines relationships between economic, ground-water and salinity, and agricultural production parameters. It will be used to help estimate the effects of one parameter on another in individual alternative plans.

The ongoing work to improve the information base and analytic tools is being done in support of formulation and evaluation of alternative plans to solve valley drainage and drainage-related problems. Major activities and milestones leading to completion and recommendation of plans include:

- A series of public meetings in fall 1989 to review the options and preliminary alternatives presented in this interim report and to discuss possible additional alternatives.
- Completion in mid-1990 of a draft report presenting a range of alternative plans.
- Public review of the draft report.
- Completion of a final report by October 1990.

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INTRODUCTION

The lack of adequate drainage has long been recognized as a serious problem for irrigated agriculture in the western and southern San Joaquin Valley. The original Federal and State plans for providing irrigation water to this area anticipated a drainage problem, and called for construction of a master drain to collect drainage from the west side of the valley and transport it to the Sacramento-San Joaquin Delta.

Eighty-five miles of the San Luis Drain (a Federal facility) was constructed between 1968 and 1975. However, the drain was never completed and terminated at Kesterson Reservoir. During the time it was operated, the drain transported drainage water from only 8,000 acres of irrigated lands. In March 1985, the Secretary of the Interior ordered cessation of drainage discharges to Kesterson Reservoir. By mid-May 1986, the feeder drains leading into the San Luis Drain and Kesterson Reservoir were plugged.

The discovery in 1983 of migratory-bird deaths and deformities linked to high selenium levels in drainage water at Kesterson Reservoir focused national attention on drainage and drainage-related problems in the San Joaquin Valley. It became clear that the valley's drainage problem involved not only agriculture, but also fish and wildlife resources, water quality, and possibly public health.

The San Joaquin Valley Drainage Program (SJVDP) was established in mid-1984 to investigate drainage and drainage-related problems and to identify possible solutions. The SJVDP is a cooperative Federal-State program, established by the Secretary of the Interior and the Governor of California. Cooperating agencies are the California Department of Water Resources,

California Department of Fish and Game, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and U.S. Geological Survey. (The SJVDP is not involved in the cleanup of Kesterson Reservoir and San Luis Drain. Those activities are being conducted by the Bureau of Reclamation's Kesterson Program.)

Specific guidance on the direction and priorities for the Drainage Program is provided by a Policy and Management Committee, composed of the Directors of the two State agencies and the Regional Directors of the three Federal agencies. A full-time, interdisciplinary staff (Study Team) made up of personnel from these same five agencies is responsible for coordination, investigative, and planning activities.

The SJVDP utilizes a wide range of technical consulting services and advisory committees. An Interagency Technical Advisory Committee provides technical advice on various aspects of the Program. The National Research Council of the National Academy of Sciences provides scientific oversight of the Program through its Committee on Irrigation-Induced Water Quality Problems. A Citizens Advisory Committee provides the Program with information and viewpoints from the broad spectrum of organizations and individuals interested in and affected by drainage and drainage-related problems.

The San Joaquin Valley Drainage Program's purpose is to identify measures to help solve immediate drainage-related problems on the west side of the San Joaquin Valley and to develop a comprehensive plan for their long-term management. Consistent with this purpose, the Program has four goals:

- Minimize potential health risks associated with subsurface agricultural drainage water.
- Protect existing and future reasonable and beneficial uses of surface and ground waters from impacts associated with drainage water.

- Sustain productivity of farmlands on the west side of the valley.
- Protect, restore, and to the extent practicable improve valley fish and wildlife resources.

In 1987, the SJVDP completed a preliminary review and screening of potential options for disposal of drainage water, including sites outside the valley. Subsequent to that screening, the Policy and Management Committee, with concurrence by the Citizens Advisory Committee, directed that investigative and planning efforts focus on in-valley solutions to the drainage-water disposal problems. (The NAS/NRC committee did not concur with this decision.) No studies of out-of-valley disposal of drainage water have been conducted since the preliminary screening, and no additional studies are scheduled for the remainder of the Program.

This report summarizes major findings and conclusions to date regarding the nature of drainage and drainage-related problems in the San Joaquin Valley, identifies a wide range of potential options for helping to manage those problems, and presents preliminary alternatives for addressing drainage problems expected to occur in the year 2000. The report will be distributed in late summer 1989 for public review and will be used as a basis for public meetings during the fall.

This report contains five chapters. Chapter 1 describes the general setting related to drainage problems. Chapter 2 provides a discussion of the various drainage and drainage-related problems, including shallow ground water, salinity in soils and water, and substances of concern, including selenium and other potentially toxic constituents. Chapter 2 also discusses findings to date on the actual and potential impacts of drainage water on public health, water quality, agriculture, and fish and wildlife resources. Chapter 3 describes some 70 options which potentially could contribute to

management of drainage and related problems. Chapter 4 illustrates how selected options can be combined into preliminary alternatives to address the unique problems of each of five geographic subareas. Chapter 5 provides a description and schedule of activities for completion of the Drainage Program by October 1990. Literature cited, a list of abbreviations, and a glossary of terms are appended.

CHAPTER 1. SETTING

California's Central Valley lies between two generally parallel mountain ranges, the Sierra Nevada on the east and the Coast Ranges on the west. The valley floor is a gently sloping, nearly unbroken alluvial plain about 400 miles long and averaging 45 miles in width. The northern part of the Central Valley (the Sacramento Valley) is drained by the Sacramento River, and about half of the southern portion (the San Joaquin Valley) is drained by the San Joaquin River. Both rivers flow into the Sacramento-San Joaquin Delta, with an outlet to the ocean through San Francisco Bay. The southern portion of the San Joaquin Valley (the Tulare Basin) is generally a closed basin with outlet to the ocean through the San Joaquin River only in extremely wet years.

STUDY AREA

Figure 1-1 shows the Drainage Program study areas. The general study area includes the entire San Joaquin Valley, from the drainage divide of the Coast Ranges to the foothills (1,000-foot elevation) of the Sierra Nevada. The valley is divided roughly in half by the San Joaquin and Tulare drainage basins.

The principal study area comprises those lands that are currently affected by or contribute to problems related to agricultural drainage, as well as lands likely to be affected in the future. Most of these lands are located on the west side of the valley from the Sacramento-San Joaquin Delta in the north to the Tehachapi Mountains in the south.

For planning purposes, the principal study area has been divided into five subareas on the basis of hydrologic considerations, political boundaries, current drainage practices, and/or the nature of drainage-related problems. From north to south, the subareas are Northern, Grasslands, Westlands, Tulare, and Kern, and are shown on Figure 1-1. Information on irrigation and drainage is presented by subarea in Table 1-1.

Table 1-1

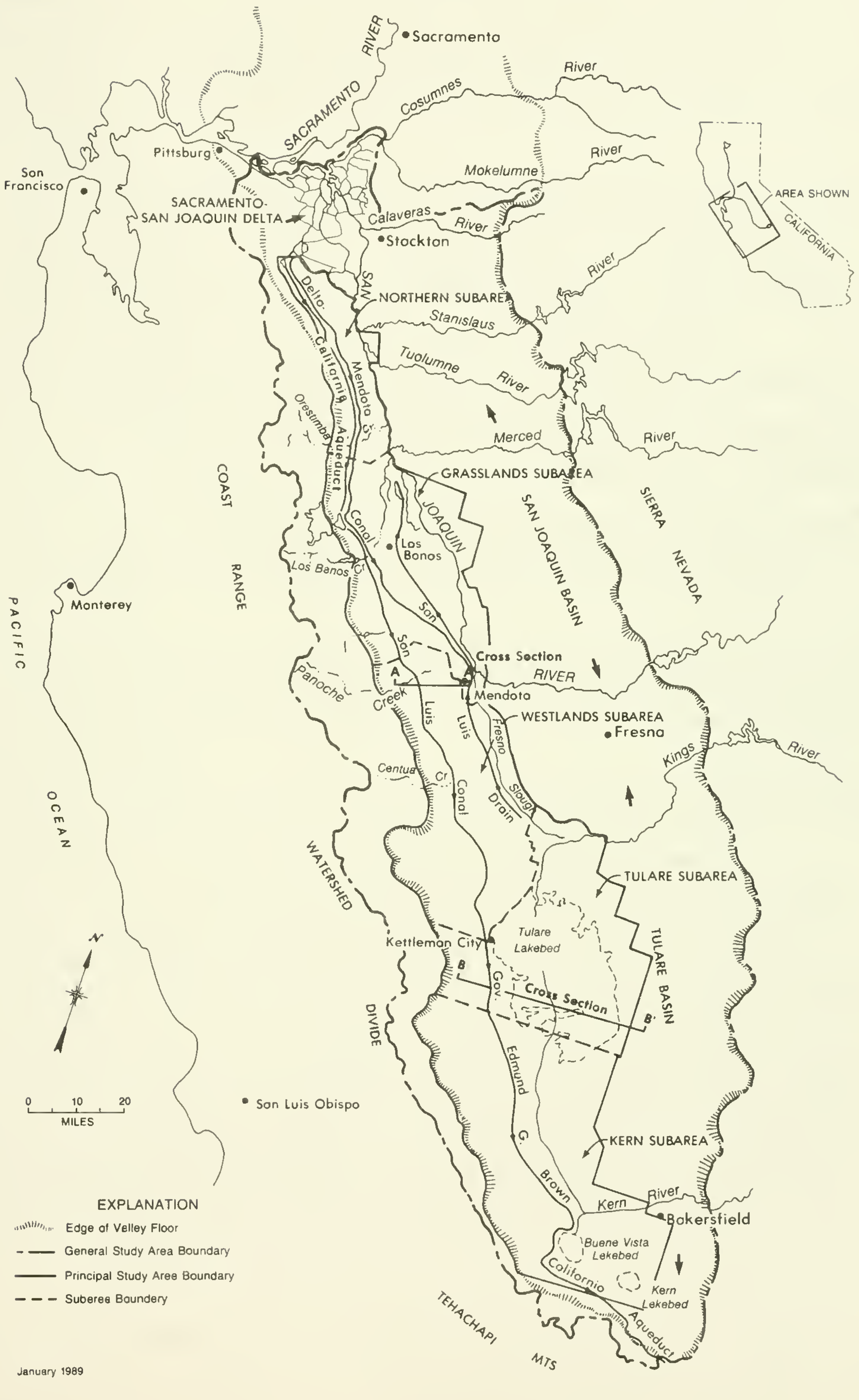
IRRIGATION AND DRAINAGE INFORMATION
(1,000 acres)

Area	Subarea					Total
	Northern	Grasslands	Westlands	Tulare	Kern	
Total area	236	707	770	883	1,210	3,806
Irrigable area	165	345	640	562	762	2,474
Irrigated area	157	311	576	506	685	2,235
Drained area	26	51	5	42	11	133

Source: U.S. Bureau of Reclamation and water district data; CH2M Hill, 1988.

Some ecologic, hydrologic, and economic factors outside the valley influence understanding of valley systems. To the extent that other areas affect or are affected by valley drainage and related problems and potential solutions, they are within the scope of the Program. Examples of such areas include the Bay-Delta region, the Pacific Flyway for migratory birds, and State, national, and world markets for valley agricultural products.

FIGURE 1-1
Program Study Areas



January 1989

GEOHYDROLOGY

A knowledge of the hydrologic and geologic characteristics of the principal study area is important for an understanding of the nature of valley drainage problems.

Precipitation in the study area is low, ranging annually from 5 inches in the south to 10 inches in the north. Virtually all of the rainfall occurs from November through April, and by midsummer the natural flow in most west-side streams has ended or diminished to little more than a trickle.

An important natural feature of the San Joaquin Valley is a geologic formation called the Corcoran Clay, which underlies all but a small portion of the study area. This layer of clay is from 20 to 200 feet thick. The bottom of the clay layer is 850 feet deep along the Coast Ranges and 400 feet deep in the valley trough. The Corcoran Clay is absent in parts of the Northern Subarea.

The Corcoran Clay layer effectively divides the ground-water aquifer into two major zones--a confined zone below the clay and a semiconfined zone above the clay (Figure 1-2).

In the San Joaquin Basin, the semiconfined zone can be divided into three geohydrologic units based on the source of the soils and sediments (Figure 1-2). These three geohydrologic units are the Coast Range alluvium, Sierra Nevada sediments, and flood-basin deposits. Coast Range alluvial deposits range in thickness from 850 feet along the slopes of the Coast Range to a few feet along the valley trough, and were derived largely from the erosion of marine rocks that form the Coast Ranges. The marine rocks contain elevated concentrations of selenium and other trace elements. The Sierra Nevada sediments, on the east side of the valley, generally do not contain

selenium. The flood-basin deposits form a relatively thin layer in the valley trough, in areas which have flooded in recent geologic time. These three geohydrologic units differ in texture, hydrologic properties, and oxidation state.

In the Tulare Basin, the semiconfined aquifer zone consists of the same three geohydrologic units found in the San Joaquin Basin plus one additional unit, Tulare Lake sediments. The Tulare Basin is characterized by the presence of several lakebeds, including Tulare, Buena Vista, and Kern (Figure 1-1).

HISTORY OF AGRICULTURE

Landholdings

Landholdings on the west side of the San Joaquin Valley have traditionally been large-scale and remain so today. After California passed from Mexican to United States rule, the U.S. Congress passed the Land Act in 1851, which contributed to the transfer of large undivided rancheros to American settlers. Also, upon admission to the Union in 1850, the State was given large tracts of land to be sold to finance State education, public buildings, and reclamation. The Swampland Act of 1850 transferred swamp and overflow lands to the State for drainage and conversion to agriculture by private interests. Large tracts of Federal land in the San Joaquin Valley also became open for settlement.

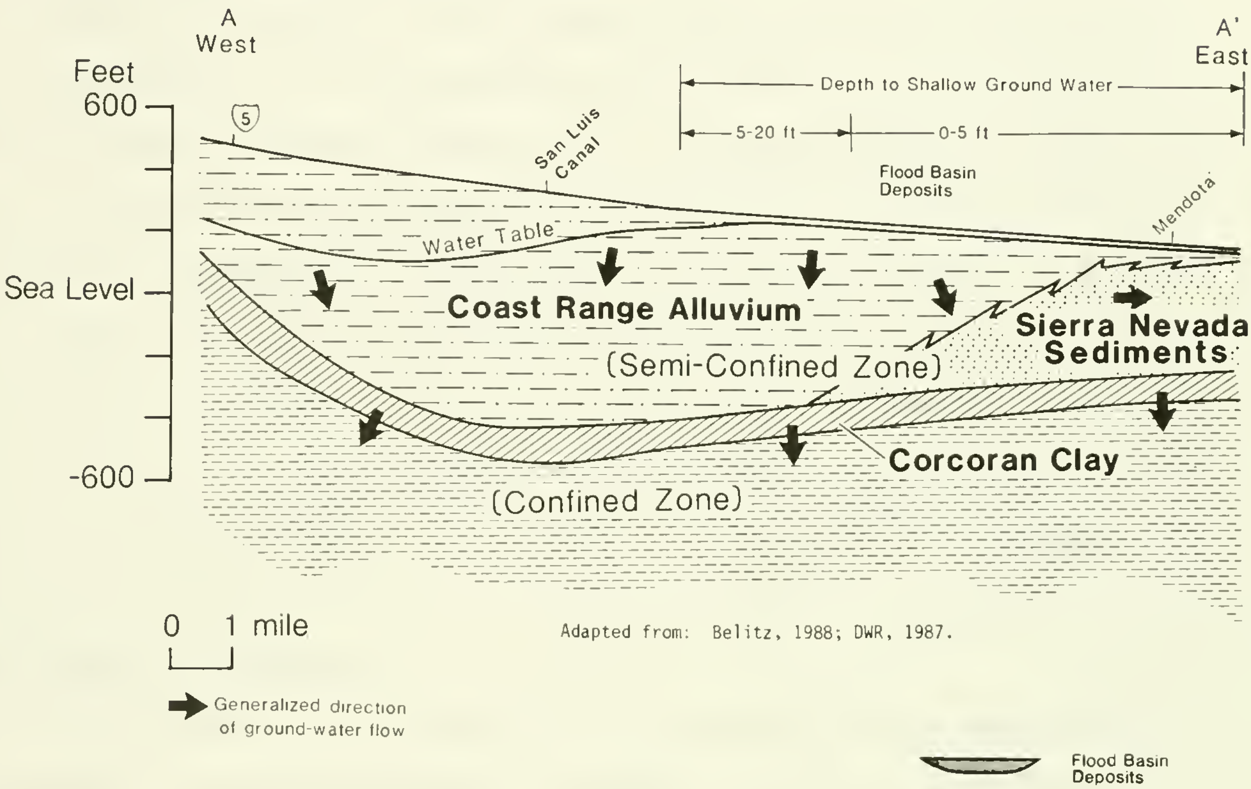
To encourage development during the 1850's and 1860's, the California legislature awarded large tracts of land (tens of thousands of acres) in the Tulare Basin to potential developers. Subsequently, the Southern Pacific Railroad was granted alternate sections of Federal land (1.6 million acres in

FIGURE 1-2

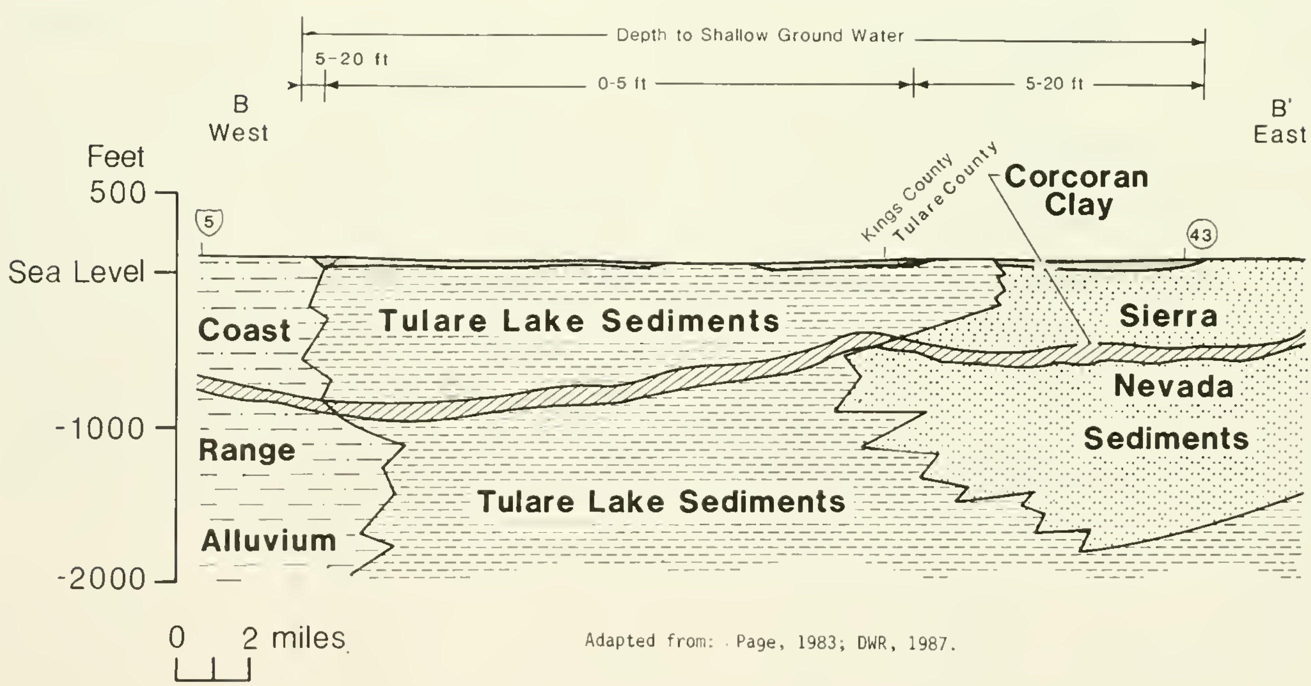
Generalized Geohydrological Cross-Sections in San Joaquin and Tulare Basins

(Locations shown in Figure 1-1)

San Joaquin Basin (Panoche Fan)



Tulare Basin



Kern County alone) as an incentive to complete a railroad through the valley. By 1875, most of the land in the San Joaquin Valley had been transferred from the Federal and State governments to private hands, with some individuals and corporations acquiring extensive holdings.

In the 1870's and 1880's, large tracts of land on the west side were put into grain production. This development was spurred by the railroad and land speculators who secured water supplies from an expanding system of ditches and canals originating from the San Joaquin and Kings Rivers. By the 1890's, the demand for irrigation water far exceeded the natural flow of the area's rivers. Many farms were abandoned around the turn of the century due to lack of adequate surface-water supplies and confusion about the legality of water rights. Also, irrigation in the area had caused the water table to rise, and as early as 1886 there were reports of soil salinization and waterlogging in low-lying areas (Ogden, 1988).

Ground-Water Overdrafting

A major factor in the development of agriculture in the valley was the improvement in pump technology during the 1930's. By the 1940's, large turbine pumps could raise water hundreds of feet, and numerous wells were drilled in the west-side Tulare Basin. By the 1950's, severe ground-water overdraft (pumping out more water than is returned to the ground water naturally) was occurring, and ground-water levels and hydraulic pressures were falling rapidly. The result was that wells had to be drilled to progressively lower depths, which increased pumping costs. There was also extensive land subsidence--a sinking of the surface of the land as underlying deposits collapsed when too much water was withdrawn. By the late 1950's, the overdraft in Kern County alone was estimated at 750,000 acre-feet per year.

Water Imports

In response to large-scale, regional problems caused by ground-water overdraft, water suppliers and water users turned to the Federal and State governments for help in developing systems for surface-water delivery to the San Joaquin Valley. In the late 1940's, the east side of the valley began to receive water from the first facilities of the Federal Central Valley Project (CVP), including Friant Dam and the Friant-Kern and Madera Canals. Friant Dam and related facilities play a role in drainage-related problems on the west side of the valley because their operation reduces the amount of water available in the San Joaquin River for instream fishery flows and dilution of drainage water discharged to the river in its lower reaches. The reduced flows due to construction and operation of Friant Dam also eliminated a number of significant fisheries in the upper river above the confluence with the Merced River, including chinook salmon and steelhead.

In 1951, following completion of the Tracy Pumping Plant and construction of the Delta-Mendota Canal (DMC), the west side of the valley began to receive CVP water developed on the upper Sacramento River. The DMC was the first of a series of Federal and State facilities bringing water to the west side of the valley, as shown in Table 1-2 and Figure 1-3.

As part of the DMC facilities, some west-side irrigators, who had formerly used San Joaquin River water, received Sacramento River water in exchange for their rights to the water now diverted into the Friant-Kern and Madera Canals which serve the east side of the valley.

The desire to obtain surface-water supplies to supplement falling ground-water levels led to the formation of several west-side irrigation districts to seek CVP water and to contract with the U.S. Bureau of Reclamation (USBR).

FIGURE 1-3
Major Federal and State Irrigation Facilities and Service Areas

Table 1-2

MAJOR FEDERAL AND STATE WATER FACILITIES AFFECTING SAN JOAQUIN RIVER AND WEST-SIDE LANDS

Facility	Primary Purpose	Completion Date
Friant Dam (CVP)	Impounds waters of the upper San Joaquin River in Millerton Lake. It controls San Joaquin River flows, providing releases for water users above Mendota Pool, flood control, conservation storage, and diversions into the Madera and Friant-Kern Canals for irrigation supplies on the east side of the valley.	1942
Tracy Pumping Plant/Delta-Mendota Canal (CVP)	Conveys CVP water for offstream storage in San Luis Reservoir (for subsequent delivery to Federal water users served by the San Luis Canal). Also conveys CVP water for direct deliveries of irrigation, municipal, industrial, and wetland water supplies to the Delta-Mendota Canal and San Luis Unit service areas.	1951
San Luis Dam and related facilities (CVP/SWP)	Provides offstream storage for the CVP and SWP for agricultural, municipal, and industrial water uses.	1967
Delta Pumping Plant/ California Aqueduct (CVP/SWP)	Conveys SWP water for storage in San Luis Reservoir and direct deliveries of agricultural, municipal, and industrial water supplies in the San Joaquin Valley and southern California. The joint-use section of the aqueduct (north of the Tehachapi Mountains) delivers CVP water to Federal customers in the western valley.	1971
San Luis Drain (CVP)	Designed to dispose of subsurface drainage water from the San Luis service area to the Bay-Delta. Part of Kesterson Reservoir, 85 miles of the drain, and a small portion of the drainage collection system were completed. The partly completed system which used Kesterson Reservoir as a terminal evaporation pond was in service from 1975 to 1986.	Incomplete

Westlands Water District was formed in 1952, Grassland Water District in 1953, and Broadview Water District in 1955. In the southern part of the study area, the Kern County Water Agency was established in 1961 to acquire water supplies for Kern County and serve as a contracting entity for water from the State Water Project (SWP).

Both the CVP's San Luis Unit and the SWP were authorized in 1960 and began delivering water in 1968. Both projects transport northern California water through the Delta to the San Luis Reservoir, a large offstream reservoir located in the Coast Range foothills west of Los Banos. Many of the water transport facilities were jointly constructed and are operated by the Federal and State governments. These include the O'Neill Dam and Forebay, San Luis Dam and Reservoir, San Luis Pumping and Generating Plant, and the San Luis Canal section of the California Aqueduct. The primary service area of the San Luis Unit is the Westlands Water District in western Fresno County. The primary irrigation service area of the SWP is in Kern County. The aqueduct serving Kern County also delivers municipal and industrial water south of the Tehachapi Mountains to southern California. Together, the Federal and State projects import about 3.9 million acre-feet of water annually to supplement inbasin ground- and surface-water supplies for irrigation of 1.6 million acres in the principal study area.

DRAINAGE HISTORY

The 1960 Federal law which authorized construction of the San Luis Unit included a requirement to "make provision for constructing the San Luis interceptor drain to the Delta" (Public Law 86-488). Drainage problems recognized by the time of authorization of the San Luis Unit included the

natural salinity of many of the desert soils, the tendency of certain clayey soils to become waterlogged when irrigated (without accompanying subsurface drainage), and the probability that any large-scale importation of water for irrigation--without related large-scale drainage service--would cause salt to accumulate in the valley in soils and ground water. At that time, drainage disposal was to be achieved by an integrated system which would include a master drain to collect drainage from the west side of the valley and transport it to the Delta. The Federal law stated that the drainage requirement could be met by the State constructing a master drain, but if the State did not, then the Federal government was to build a drain. In 1962, after the State informed the Federal government that it could not construct a master drain, the Secretary of the Interior informed Congress that the USBR would construct a drain. However, several significant changes were made in the concept of the drain.

The original feasibility report for the San Luis Unit, which preceded passage of the authorizing legislation, described an earthen ditch serving 96,000 acres of land (USBR, 1955). In 1962, the USBR completed a new report in response to concerns over the possibility of two separate drains (one Federal and one State) and concerns about the effects of discharging agricultural drainage in the Delta. The USBR's plans called for a concrete-lined drain serving 300,000 acres of land. This report discussed building holding ponds for temporary retention of drainage water when the interceptor drain was full, thus allowing a reduction in the design capacity of the interceptor drain. The ponds could also be used to evaporate some of the drainage water, promote the growth of vegetation in wildlife areas, and provide temporary storage of drainage water until completion of the drain to the Delta.

In 1965, the State indicated it wanted to participate in a single valley-wide master (interceptor) drain, and the USBR revised its program accordingly. Although this eliminated a potential problem of two separate drains, there continued to be concerns about the potential effects on the quality of Delta and San Francisco Bay water of discharges of untreated drainage water. In October 1965, Congress included a rider to the CVP appropriations act specifying:

> That the final point of discharge for the interceptor drain for the San Luis Unit shall not be determined until development by the Secretary of the Interior and the State of California of a plan which shall conform with the water quality standards of the State of California as approved by the Administrator of the Environmental Protection Agency, to minimize any detrimental effect of the San Luis drainage waters.

This or similar language has been in the annual appropriations act for the CVP every subsequent year.

In 1967, the State again declined participation in a valley-wide master drain, so the USBR proceeded alone with plans to provide drainage for the San Luis Unit. Construction of the San Luis Drain began in March 1968. By 1975, 85 miles of the drain, 120 miles of collector drains, and the first phase (about 1,200 acres) of a regulating reservoir, later named Kesterson Reservoir, were completed. In 1970, Kesterson Reservoir was designated as part of a new national wildlife refuge under joint management by the USBR and the U.S. Fish and Wildlife Service (USFWS). Construction of the remainder of

the reservoir and the remaining section of the drain to the Delta was then delayed because of Federal budget restrictions and increasing environmental concerns regarding drainage-water discharges to the Delta. Without completion of the drain, Kesterson Reservoir served as an evaporation pond for drainage water from a few thousand acres of irrigated land.

In 1975, the USBR, the California Department of Water Resources (DWR), and the State Water Resources Control Board (SWRCB) formed the San Joaquin Valley Interagency Drainage Program (IDP) to find an economically, environmentally, and politically acceptable solution to valley drainage problems. The IDP recommended completion of the drain to a discharge point in the Delta near Chipps Island.

In order for drainage water to be discharged into the Delta, the USBR was required to obtain a discharge permit from the SWRCB, which also held delegated permit-authority from the U.S. Environmental Protection Agency (EPA). The process of developing criteria for the permit was delayed until after the IDP report was completed in 1979. In 1981, the USBR began the San Luis Unit Special Study to fulfill SWRCB permit requirements. In 1983 the USBR was advised of bird deformities and deaths at Kesterson Reservoir. Subsequent studies (1984) showed that the severe effects were likely caused by selenium poisoning.

In mid-1984, then-Secretary of the Interior William Clark and California Governor George Deukmejian agreed to establish the Federal-State San Joaquin Valley Drainage Program. The purpose of this program, as stated by Secretary Clark, was to conduct "comprehensive studies to identify the magnitude and sources of the drainage problem, the toxic effects of selenium on wildlife, and what actions need to be taken to resolve these issues."

In March 1985, the Secretary of the Interior, concerned that continued operation of the reservoir might constitute violation of the Federal Migratory Bird Treaty Act, ordered the cessation of subsurface drainage discharge to Kesterson Reservoir. The pipelines which conveyed the drainage water to the San Luis Drain were plugged by mid-May 1986. Kesterson Reservoir has been closed, and emergent vegetation was plowed under and low-lying areas in the reservoir were filled in the summer and fall of 1988.

Additional pressure to resolve the drainage problem resulted from a lawsuit brought by the Westlands Water District against the Department of Interior. A final decision by the Court has been placed in abeyance under an agreement between Westlands and the Department. Under this agreement, the Westlands Water District, the chief beneficiary of the San Luis Unit, will make trust fund deposits totaling up to $100 million. These funds are to implement a drainage management plan for Westlands which is to be developed by the USBR. The USBR is to produce an "acceptable and approved" plan by December 31, 1991, or the funds collected may be returned to the district and the case will proceed in the courts.

Parts of the Tulare Basin, much of which is served irrigation water by the SWP, has also been long affected by drainage problems. The Burns-Porter Act authorized construction of facilities for removal of drainage water from the San Joaquin Valley in the construction of the SWP, indicating a long-recognized need for a drainage solution. The pressures of the need for drainage in the State service area have recently intensified with the observation of wildlife deformities and deaths at evaporation ponds receiving drainage water.

AGRICULTURAL DEVELOPMENT

Although much of the information in this section is preliminary, it is important at this time to present a picture of agricultural development characteristic of the principal study area. Sandra Archibald of the Stanford Food Institute is conducting a study which will provide the SJVDP later in 1989 with additional and more current information concerning agriculture in the San Joaquin Valley. Her study addresses the pattern of agricultural development, including the service sector, since the introduction of large-scale irrigation; patterns of resource development and use, including future trends; and issues affecting the future of agriculture in the valley.

Value of Agricultural Production

The economy of the west-side San Joaquin Valley is almost totally dependent on irrigated agriculture. Out of a total of 2,474,000 irrigable acres in the principal study area, more than 90 percent of the lands are in irrigated agriculture at any point in time, and some of the remainder are irrigated lands which are temporarily fallow. The gross market value of crops produced in the study area exceeds $2 billion annually (USBC, 1982).

As with all economic activities, there is also a "multiplier" effect from agricultural production. Each dollar generated in agriculture produces a ripple effect through the economy, multiplying several times. In 1980, the DWR published the results of input-output studies evaluating the multiplier effect. The multiplier varied depending on the crop, ranging from a low of 2.83 for cereal grains (meaning each $1 of cereal grain generates a total of $2.83 in the economy as a whole) to 3.24 for fruits (DWR, 1980). Based on this multiplier effect, the total economic contribution of crops produced in the study area exceeds $6 billion annually.

Size and Type of Farm Operations

Farm size varies in the respective subareas (see Table 1-3) and is largely associated with the type of farming operation. Farms tend to be comparatively small when based upon orchards and vegetable cropping (such as in the Northern Subarea) and larger where farming is largely field crops. Farm size is also affected by the Reclamation Reform Act. Additional information about farms in the study area is being gathered to learn more about the farming operations in each subarea. This information may be important to determining the willingness of growers to accept irrigation and drainage innovation, or growers' ability to absorb additional costs for drainage treatment or disposal.

Table 1-3

ESTIMATED FARM SIZE IN THE PRINCIPAL STUDY AREA
(1987 data)

	Full-Time Farms	
Subarea	Number	Average Size (acres)
Northern	1,090	180
Grasslands	1,080	630
Westlands	695	870
Tulare	800	1,000
Kern	1,130	850

Source: Reports of County Agricultural Commissions adjusted to reflect subarea boundaries.

Fixed Investment

Another factor which reflects the kind of farming and likely future investment in irrigation and drainage management systems is the amount of fixed investment. This includes the cost of buildings, land, and improvements such as drains or fixed irrigation systems. Table 1-4 shows the fixed agricultural investment in each subarea.

Table 1-4

ESTIMATED FIXED PRIVATE INVESTMENT IN IRRIGATED AGRICULTURE IN THE STUDY AREA[a] (In 1982)

Subarea	Acreage Irrigated	Average Investment/Acre($)	Estimated Total Investment($)
Northern	157,000	3,471	544,947,000
Grasslands	311,000	2,858	888,838,000
Westlands	576,000	3,351	1,930,176,000
Tulare	506,000	2,699	1,365,694,000
Kern	685,000	2,237	1,534,582,000
TOTAL	2,235,000		6,264,237,000

[a] Table constructed from information from Boyle Engineering Corp., 1988a: page 40. "West San Joaquin Valley Agricultural Setting."

Types of Crops

The distribution of crops in 1985 within the Federal and State service areas is shown in Table 1-5.

Table 1-5

DISTRIBUTION OF CROPS IN FEDERAL AND STATE SERVICE AREAS
(1985 data)

Crop	Acreage	Gross Market Value	
		Per Acre($)	Total Value($)
Cereal Grains	200,110	288	57,623,000
Forage Crops	101,878	597	60,793,000
Field Crops	690,802	717	494,775,000
Vegetables	212,660	2,131	453,149,000
Nursery	4,261	23,735	101,134,000
Seeds	38,156	680	25,964,000
Fruits	91,883	2,068	190,037,000
Nuts	75,944	837	63,581,000
Family Gardens and Orchards	21	2,714	57,000
TOTAL	1,415,715		$1,447,113,000

Source: Boyle Engineering Corp., 1988a: page 27.

Although Table 1-5 does not include all the irrigated lands in the study area, the data do suggest the diversity and distribution of crops. There are, of course, variations in the distribution of crops among the five subareas. Fruits and nuts, for example, are important crops in the Northern, Grasslands, and Kern Subareas. The predominant crops in Westlands are field crops and cereal grains, although vegetable production is also significant. In Tulare, field crops are the most important. For both Westlands and Tulare, cotton is the most important field crop.

Irrigation Practices

Current irrigation practices in the San Joaquin Valley and California are outlined in Table 1-6. Information in the table indicates that surface

irrigation remains the predominant irrigation practice. The selection of irrigation methods is mainly an economic decision balancing irrigation (facilities and management costs) with water cost, drainage management cost, and crop production. The selection of method and the comparative efficiencies achieved by growers is affected also by differences in soil type, climate, slope, crops grown, and grower experience.

Table 1-6

IRRIGATION METHODS IN THE SAN JOAQUIN VALLEY AND CALIFORNIA, 1972 and 1980

	San Joaquin Valley (1,000 acres)			California (1,000 acres)		
Irrigation Method	1972	1980	% Change	1972	1980	% Change
Surface:						
Flood	--	5	--	210	260	23.8
Border	2,120	1,860	-12.3	3,650	3,210	-12.1
Basin	40	255	537.5	340	730	114.7
Furrow	1,730	2,430	40.5	3,150	3,600	14.3
Subtotal	3,890	4,550	17.0	7,350	7,800	6.1
Sprinkler:						
Solid Set	160	145	-9.4	310	395	27.4
Hand-Move	430	565	31.4	1,120	1,035	-7.6
Mechanical-Move	30	85	183.3	140	305	117.9
Subtotal	620	795	28.2	1,570	1,735	10.5
Drip Irrigation	10	135	250.0	30	260	766.7
Subsurface Irrigation	10	40	300.0	100	125	25.0
TOTAL	4,530	5,520	21.9	9,050	9,920	9.6

Source: Boyle Engineering Corporation, 1986: pages 4-8. "Evaluation of On-Farm Agricultural Management Alternatives."

It is not possible to achieve total irrigation efficiency (meaning all the water applied to the crop is used by the crop) and continue to maintain

production. Additional water to leach salts from the crop root zone is essential to maintain agricultural productivity. Typically, 0.2 acre-foot per acre is an adequate amount of water applied for leaching purposes.

There are significant differences in the efficiency of irrigation from one subarea to the next, and even within each subarea. Preirrigation is one practice which produces substantial volumes of drainage water. Preirrigation is the irrigation of a field prior to the growing season in order to create a reservoir of soil moisture for seeding and future water needs of the growing plant, and to leach salts from the root zone.

The amount of preirrigation is influenced by three factors. First, there is the tendency to assure that the entire root zone of crops to be grown is filled to capacity since many fine-textured soils on the west side will not allow enough water to penetrate to fill the root zone after the first irrigation. Second, growers want to use all the water for which they have paid. Third, there is always a tendency to protect against the dangers of a dry year by preirrigating as if each year were going to be dry.

Another fundamental issue is off-site effects produced by irrigating a field. Downslope lands tend to be affected by upslope practices. For example, there are fields where growers who have not irrigated for days receive an influx of drainage water into their subsurface drains when a neighbor irrigates. In some areas, this shallow ground water carries high concentrations of salts and trace elements such as selenium.

Irrigation Water Costs

Costs of State and Federal project irrigation water deliveries from the Delta vary widely among water districts and subareas and, in general, according to the comparative age of the project supplying the water; i.e., the earlier the initiation date of the project, the cheaper the water. Each

succeeding project tends to show increased construction costs and economic inflation. Also, growers receiving water from the CVP generally pay less than State water contractors because of the larger irrigation subsidy provided under Federal reclamation law. In some subareas, pumping costs to bring the water uphill from CVP or SWP canals are a significant part of total water cost. The range of project water costs within subareas is shown in Table 1-7.

Table 1-7

PROJECT IRRIGATION WATER COSTS
(Delta Deliveries Only)

Subarea	Grower Water Cost in 1985[a] (dollars per acre-foot)
Northern	16.50 - 18.00
Grasslands[b]	19.50 - 25.00
Westlands	17.85 - 50.00
Tulare	45.50 - 50.00[c]
Kern	45.50 - 50.00[c]

[a] Some areas have additional local assessments of $10 to $30 per acre-foot for operation and maintenance.
[b] Does not include lands supplied water through exchange contracts.
[c] In some districts, pumping costs push rates to a total of $87 to $127 per acre-foot.

Source: Boyle, 1988a, page 52.

THE INSTITUTIONAL SETTING

There are numerous laws and institutional arrangements which either contribute to drainage and related problems or may be important to the solution of such problems. The following description of the most important institutional issues is incomplete; however, studies are under way to fill in many gaps, and the preliminary results will become available in late-1989.

Evaluations will be made of the potential impact of various laws (e.g., Federal Migratory Bird Treaty Act, California Toxic Pits Cleanup Act) and the potential opportunities for solving drainage problems through institutional means (e.g., increasing the powers and responsibilities of water districts).

Water Rights

Agriculture in the San Joaquin Valley first developed near perennial streams. In some cases, canals were constructed for delivery of river water to irrigate lands some distance away. The rights of streamside landowners to river water are riparian rights. Today, however, most irrigated farmlands in California use water that has been developed (stored and transported) from remote rivers. The rights to this water are governed by a parallel system of laws based on priority of use. Although this appropriative water law system gives priority to senior water users, no user may claim an amount of water beyond that which is used beneficially. The right is maintained by consistent annual use and may be lost through nonuse.

In the study area, irrigation water is provided under contracts from the Federal and State Water Projects. The projects acquired the right to this water in two ways: (1) By appropriation, for which they hold State permits, and (2) by exchange of water entitlements for rights previously held by private parties. As a result, in most areas of the valley surface-water appropriative rights are now held by the Federal government or by State-chartered organizations such as the Kern County Water Agency.

The term "water right" might more appropriately be described as "water-use right" because the right holder does not own the water itself, but only has a right to its use. The water itself is owned by the public and administered by the State of California. While this distinction may seem hypothetical, it plays an important role in California's system for allocating

water among competing interests. Recent decisions by the SWRCB, the State agency responsible for administering water rights and water-quality law, and by several appellate courts in California have established that water rights may be altered as necessary to protect "public trust" resources such as fish and wildlife. The water rights held by the CVP and SWP (with the exception of riparian and pre-1914 appropriative rights) are thus conditional rights, and the SWRCB has authority to revise their terms.

In 1978, the SWRCB issued Decision 1485, which set salinity and flow standards for the Sacramento-San Joaquin Delta and Suisun Marsh. In order to meet these standards in dry years, it is necessary to reduce deliveries of water in both the CVP and SWP systems. This decision set off a legal debate between the State and Federal projects which was finally resolved by the Coordinated Operation Agreement, approved by the Congress and the State of California. The SWRCB is required to reconsider its decisions every 3 years and hold hearings on salinity and flow standards every 10 years. The salinity and flow regime developed in the original decision (D-1485) was held to be legally inadequate to protect the full range of water-quality values for the entire Sacramento-San Joaquin Estuary (United States v. State Water Resources Control Board [1986]), and the SWRCB is currently holding hearings to develop a more "globally balanced" regime. It is possible that the new regime will necessitate a reordering of existing water uses and rights to meet water-quality standards and/or protect or restore fish and wildlife resources.

Agricultural Subsidies

Irrigation water supplied by both the CVP and SWP involves subsidy elements. The original Federal reclamation law was designed to promote the agricultural development of the arid west and to encourage family farmers to settle on the land. One of the mechanisms was water subsidies, whereby

farmers paid less for irrigation water than the cost of developing and conveying it to the farmlands.

Although a basic principle in Federal water contracting has been that water users repay project costs, reclamation law and policy have limited farmers' repayment obligations to an amount less than "full cost" repayment. Project costs consist of the costs to: (1) Construct physical facilities, such as dams, canals, and pumping plants, and (2) operate, maintain, and replace the physical works. While annual operation costs are to be fully repaid, construction costs are repaid exclusive of an interest component, provided the grower meets applicable legal requirements. In addition, repayment of the construction cost element is limited to "payment capacity," which is the maximum amount farmers can afford to pay given the productivity of their land and crops. Federally supplied hydroelectric power is also available to grower water districts at less than private rates.

One unintended subsidy is being corrected as existing water contracts are being renegotiated. Early CVP water contracts contained fixed water repayment rates, and with inflation over the years, the amount specified in the contracts was no longer sufficient to pay both the construction (limited by payment capacity) and operation and maintenance costs. Deficits in the operation and maintenance repayment accounts began to accumulate. Future Federal contracts will contain provisions to escalate water rates to ensure the repayment of operation and maintenance costs in full.

Contracts for SWP water also contain a subsidy element because the interest rate used in calculating water repayment rates is less than the market interest rate.

Some of the crops grown in the study area also are eligible for commodity price support programs of the U.S. Department of Agriculture designed to stabilize the prices and production of selected crops.

Reclamation Reform Act

The purpose of the Federal reclamation program was both to settle the arid west and to support family farming. Farmers owning 160 acres or less (320 acres for a married couple) were eligible to receive Federally subsidized water. Because of the history of agricultural development along the west side of the San Joaquin Valley, many of the farms were very large, with some holdings exceeding 10,000 acres. They existed before Federally supplied import water was available to the area and relied on ground water as the irrigation supply. In order to receive Federal irrigation water for land in excess of 160 acres (or 320 acres), the owners of these large farms had to sign "recordable contracts" which required that land in excess of 160 acres (or 320 acres) be sold within 10 years at a price, approved by the Secretary of the Interior, that did not reflect the benefits conferred by the Federal water.

In 1982, Congress passed the Reclamation Reform Act, increasing the largest farm eligible for Federally subsidized water to 960 acres. Farms larger than 960 acres are required to pay higher water rates for the acreage in excess of 960 acres. The 1982 act also limited the amount of land that could be leased and still receive the irrigation water subsidy.

Water Utility Districts

A water utility district is a type of special district. Special districts are local government subdivisions of the State of California that are neither cities, counties, nor school districts. The State specifies the purposes and procedures for incorporating special districts through general

and special legislative enabling acts. Special districts that provide water services, or water utility districts, serve as a focal point for agricultural water planning, policy, and day-to-day management. These water utility districts administer local agricultural water utility services and provide important organizational linkages among water users and other governmental entities in the region.

The authority of water utility districts is limited to powers and activities specifically enumerated in enabling statutes. Enabling statutes often allow different types of districts to pursue related primary and secondary purposes. Many districts are principally empowered to acquire, develop, and distribute water for beneficial purposes to users within the district. Other districts are principally concerned with draining or reclaiming agricultural land, which may also be a secondary purpose of other districts. Additional primary or secondary purposes include the conservation and development of soil and water resources, development of hydroelectric power, and provision of recreational facilities. Water utility districts in the study area also vary according to relative autonomy of the district's governing board, voting procedures, and sources of revenue (Coontz, 1989).

FISH AND WILDLIFE RESOURCES

Studies have revealed severe drainage-related impacts to wildlife at a number of sites on the west side and southern end of the San Joaquin Valley. An understanding of the status of fish and wildlife resources in the San Joaquin Valley is necessary to fully comprehend the present and future effects on fish and wildlife of the agricultural drainage water produced in the valley. Following is a discussion of the historic and current quantity and quality of fish and wildlife habitats and populations in the valley.

Historic Fish and Wildlife Habitats and Populations

Historically, regular seasonal flooding of large areas of the San Joaquin Valley floor created a lush patchwork of aquatic, wetland, riparian forest, and valley oak savannah habitats. Surrounding these overflow lands were vast stretches of California prairie and San Joaquin saltbush. Within the San Joaquin Basin, the San Joaquin River, fed by major tributaries on the east side of the basin, emptied into the San Francisco Bay through the San Joaquin Delta. The San Joaquin River seasonally overflowed its banks, creating vast areas of wetlands and associated aquatic habitats. In contrast, river runoff in the Tulare Basin (which lacks a perennial surface-water outlet) supported Tulare Lake, four smaller lakes, and a vast network of interconnected sloughs, riparian forests, and wetlands. Prior to the damming of the Kings, Kaweah, Tule, and Kern Rivers, Tulare Lake (on a surface-area basis) was the largest freshwater lake west of the Mississippi River (Schroeder et al., 1988). At its highest recorded water level (e.g., during 1853, 1862, 1868), Tulare Lake was about 40 feet deep and flooded about 760-800 square miles (Alexander et al., 1874; Hall, 1886; Thompson, 1892; USBR, 1970; USFWS, 1978). Under extended drought conditions, Tulare Lake was known to evaporate completely (Latta, 1949). Nonetheless, on average during the past few thousand years, all five lakes in the Tulare Basin covered between 800 and 1,000 square miles (Alexander et al., 1874; USBR, 1970; USFWS, 1978).

The rich diversity of habitats in both basins supported large populations of resident and migratory species of fish and wildlife. When the water levels in the Tulare Basin were sufficient to provide a surface-water connection to the San Joaquin River system (more than half of the years between 1850 and 1872 [Harding, 1949 in USBR, 1970; Warner and Hendrix, 1985]), anadromous fishes arrived in great numbers and provided food for basin residents. During

the late 1800's, Tulare Lake also supported a small commercial fishery for western pond turtles and native minnows (Moyle, 1976). Additionally, enormous numbers of waterfowl and fur-bearing mammals were commercially harvested in the San Joaquin Valley through the late 1800's (Ogden, 1988).

Current Wildlife Resources and Endangered Species

Widespread conversion of native lands to agricultural, municipal, and industrial uses has reduced several of the once valuable and productive habitats to the point of endangerment. For example, Federal legislation in 1850 encouraged the conversion of swamp and overflow lands to agricultural use. As a result, most of the bottom-land habitats which included wetlands, riparian forest, and valley oak savannah have been lost. Approximately 13 percent of the original wetland habitat and only 7 percent of the riparian forests (including valley oak savannah) remain in the San Joaquin Valley. In the Tulare Basin, as a consequence of dams and diversions of east-side rivers and draining and "reclamation" of the once expansive historic lakes, only 3 percent of the wetlands remain.

Wetlands in the San Joaquin Valley provide essential habitat for birds of the Pacific Flyway, the migratory path of ducks and geese that annually fly across the western United States from Canada, Alaska, and the Arctic in the north, to southern California and Mexico in the south. Approximately 10-12 million ducks and geese, accompanied by hundreds of thousands of other birds, annually winter or pass through the Central Valley of California.

Significant habitat loss in the San Joaquin Valley has resulted in the decline of a number of species of plants and animals endemic to the valley. Of the 26 State and 15 federally listed endangered species which occur in the valley, 2 species are primarily associated with wetlands, 4 species with vernal pools, 3 species with riparian forest and valley oak savannah,

10 species with California prairie, 6 species with San Joaquin saltbush, and 3 species with Antioch dunes, a remnant coastal strand sand-dune habitat in the northernmost part of the valley. Further, many species of birds which were historically residents now occur in much reduced numbers as summer non-breeders, winter visitors, or transients. Additionally, species such as the grizzly bear, prong horn antelope, and gray wolfe were extirpated from their range in the San Joaquin Valley, while the Tule elk escaped extinction by being maintained in captivity.

Current Fishery Resources

The loss of the once extensive lakes, drastically reduced instream flows (as a result of diversions, interbasin water transfers, and management of water storage projects), and declining water quality (from contamination by municipal, industrial, and agricultural wastes, and other human activities) have taken a substantial toll on the fisheries of the San Joaquin Valley.

The San Joaquin River and its tributaries have been modified to the extent that major changes have occurred in fish communities. Today, the dominant fishes are introduced species, with native fishes reduced to a minor part of the fauna. Native anadromous species such as chinook salmon, which once were abundant and consisted of at least two runs (spring and fall), now occur in significantly reduced numbers, and exist in only four of the major east-side tributaries to the San Joaquin River. Since the completion of Friant Dam, chinook salmon have appeared in the upper main stem of the San Joaquin River only in extremely wet years (Moyle, 1976). The thicktail chub, historically one of the most abundant native endemic fishes in the sloughs and lakes of the San Joaquin Valley, is now believed extinct (Brown and Moyle, in press).

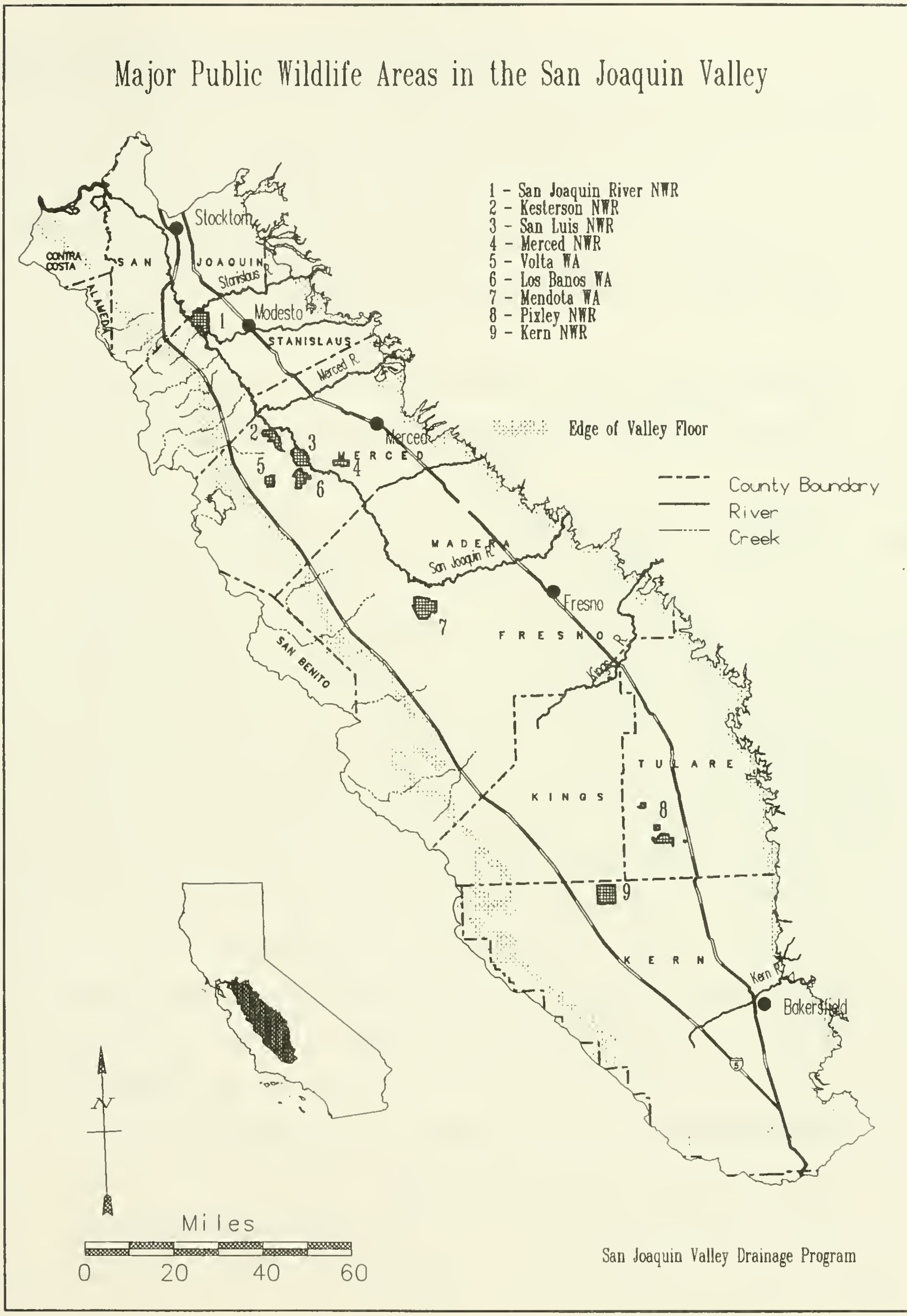
Wildlife Areas and Fisheries Facilities, and Water Supplies and Needs

Portions of remaining native habitats in the San Joaquin Valley are protected within parks, refuges, and preserves. Approximately 190,000 acres of public and private land and water areas in the valley are managed primarily for the benefit of fish and wildlife. Such areas include Federal and State wildlife areas, State fishery facilities, private duck clubs, special management areas on other public lands, and private nature preserves. Figure 1-4 shows the locations of major public wildlife areas in the San Joaquin Valley.

Drainage water in the San Joaquin Valley was previously used to satisfy some of the water needs for public and private wildlife areas, and still provides instream flows in the San Joaquin River and many west-side tributaries. The SJVDP has calculated that use of agricultural drainage water on public and private wildlife areas in the valley during the late 1970's to mid-1980's was approximately 122,000-136,000 acre-feet per year (about 52 percent of all firm water supplies used on these areas). Use of untreated drainage water for such purposes may pose a serious threat to fish and wildlife health, and has been discontinued as a wetland water supply on almost all wildlife areas. However, both the instream fishery flow needs and the volumes of drainage water that satisfy some of those needs are as yet unknown.

Existing wildlife-wetlands areas on the valley floor need approximately 437,000-441,000 acre-feet per year of freshwater annually to satisfy optimum management needs. Reliable firm supplies of freshwater for these areas currently total approximately 128,000 acre-feet per year (about 29 percent of needs). The deficit of firm freshwater supplies to existing wildlife areas in the San Joaquin Valley is equal to 279,000-313,000 acre-feet per year.

FIGURE 1-4


Major Public Wildlife Areas in the San Joaquin Valley
1 - San Joaquin River NWR
2 - Kesterson NWR
3 - San Luis NWR
4 - Merced NWR
5 - Volta WA
6 - Los Banos WA
7 - Mendota WA
8 - Pixley NWR
9 - Kern NWR
Edge of Valley Floor
County Boundary
River
Creek
Stockton
Modesto
Merced
Fresno
Bakersfield
CONTRA COSTA
SAN JOAQUIN
ALAMEDA
STANISLAUS
MERCED
MADERA
FRESNO
SAN BENITO
TULARE
KINGS
KERN
Stanislaus R.
Merced R.
San Joaquin R.
Kings R.
Kern R.
N
Miles
0
20
40
60
San Joaquin Valley Drainage Program

Economic Value of Fish and Wildlife Resources

The economic values of the valley's fish and wildlife resources and their associated habitats are being evaluated by the SJVDP. The value of environmental amenities involves estimating the following:

- o Public recreation value, which measures users' willingness to pay for recreation opportunities such as hunting, fishing, and nature observation.
- o Existence value, which is the economic benefit society receives from simply knowing that environmental amenities in the valley continue to exist now and in the future.
- o Option value, which refers to the public willingness to pay to assure the availability of environmental resources in the valley for their possible use in the future.

The above types of values are being estimated for San Joaquin Valley fish and wildlife resources. They are net values and measure the economic contribution of these resources to the nation as a whole. The methodology used to estimate these values is similar to a public opinion poll which asks people how much they would be willing to pay to improve resources or how much they would need to be paid to give up (or "sell") a resource. The first approach is known as "willingness-to-pay" and the second as "willingness-to-sell." Application of both methods has shown that the "willingness-to-sell" approach typically results in higher values when the very existence of a resource is threatened.

Activities associated with environmental resources also have effects on local, regional, and the State economies. Hunting and fishing activities along the west side of the valley contribute to economic activity in the region, and two frequently used indicators are employment and income. Direct

local impacts include effects resulting directly from spending by hunters, anglers, and nature observers in the local area. Total impacts include multiplier or "ripple" effects throughout other sectors of the local economy affected indirectly by these expenditures. These values will be estimated in conjunction with the indirect values associated with agricultural activities.

A recent compilation of research on fish and wildlife values in California (Cooper and Loomis, 1988) noted that the net economic value of waterfowl hunting in the Central Valley and elsewhere ranged from approximately $37 to $70/hunter/day. Total value to waterfowl hunters (the willingness-to-pay beyond their current level of hunting-related expenditures, such as travel and lodging) can be found by multiplying the daily use value by the total number of hunter-days. No data are currently available on the net value to anglers for fishing in the San Joaquin River and its tributaries (including canals and sloughs). One estimate of the net value per day that people in California place on birdviewing ranges from $8 to $16.

Net economic values for selected fish and wildlife resources in the San Joaquin Valley are being investigated by the SJVDP and will be available later in 1989. The study will also estimate the values society places on the continued existence of fish and wildlife resources, associated habitats, and use opportunities.

CHAPTER 2. PROBLEM DEFINITION

Drainage and drainage-related problems in the study area are caused by three generally interrelated conditions: (1) Shallow ground-water levels, (2) high salinity, and (3) elevated concentrations of selenium and other toxic or potentially toxic trace elements. This chapter discusses drainage and related conditions and problems and their impacts as related to the Program's four goals concerning public health, water quality, agriculture, and fish and wildlife resources.

DRAINAGE AND RELATED CONDITIONS AND PROBLEMS

Shallow Ground Water

Much of the irrigation water applied to valley agricultural lands is consumed by plants and evaporates from the soil or plant surfaces through evapotranspiration, or "ET." One of the results of ET is an accumulation of salts within the crop root zone. An additional amount of water, in excess of plant ET, is applied to leach (flush) these salts from the root zone and transport them down into the subsurface or out through tile drains.

The term "salt balance" is used to describe an ideal condition in which there is no accumulation of salt in the root zone from one year to the next. Normally, the amount of leaching water required to maintain this salt balance varies from 0.1 to 0.3 acre-foot/acre of land. However, the efficiency of irrigation systems used to apply water and the variability of soil-water intake rate are such that the water applied to the land is considerably more than is necessary to maintain a salt balance. Water in excess of plant

requirements passes through and beneath the crop root zone and is referred to as "deep percolation."

Deep percolation adds to the ground water which fills underground pore spaces in gravel, sands, silt, and clay. As shown in Figure 1-2 and discussed in Chapter 1, there are two major ground-water aquifer zones: the semiconfined and the confined, which are separated by the Corcoran Clay. The Corcoran Clay restricts but does not totally prevent movement of water between the upper semiconfined and lower confined zones. In much of the study area, particularly the San Joaquin Basin, the semiconfined zone is saturated with water from the land surface down several hundred feet to the Corcoran Clay. In this report, the term "shallow ground water" describes a condition in which the water table in the semiconfined zone is within 20 feet of the surface of the land.

Historical patterns. Agricultural activity in the study area began in the 1870's, and large-scale irrigation started during World War I. By the early 1950's, agriculture was using 3 to 5 million acre-feet of ground water each year. Most of the ground water was pumped from the confined zone (Prokopovich, 1989). The primary method of recharging the ground-water aquifers was through deep percolation, and during the 1950's and early 1960's much more water was being pumped than was being recharged by deep percolation.

Between 1952 and 1967, the piezometric surface of the confined aquifer (the level to which water from the confined zone would rise in a tightly cased well) had dropped hundreds of feet (Belitz, 1988). Pumping lifts from the confined aquifer exceeded 800 feet over part of the area, and land subsidence of more than 2 feet occurred throughout the study area, with as much as 28 feet in localized areas (Prokopovich, 1989).

To offset the ground-water overdraft problem, beginning in the 1950's large volumes of surface water were diverted from the Delta and imported into the study area through facilities of the CVP and the SWP. This resulted in an increase in the total amount of water applied to agricultural land and a decrease in the amount of water removed from ground-water aquifers. In the years since, pressure levels have increased in the confined aquifer and the water table in the semiconfined aquifer has risen sharply (Prokopovich, 1989). In the valley trough, the pressure surface increased an average of 100 feet between 1961 and 1984 (pers. comm., K. Belitz, U.S. Geological Survey, Sacramento, California).

Increased rates of ground-water recharge due to deep percolation of irrigation water, together with decreased pumping since 1968, have caused a rise in the elevation of the water table in the semiconfined aquifer over much of the central portion of the west side of the valley. In 1984, approximately one-half of the study area was characterized by a water table within 20 feet of the land surface, whereas in 1952 only a small percentage of the west side was underlain by such shallow ground water. Shallow ground water creates a number of problems for valley growers. Crop productivity will decline when the root zone is saturated for long periods during the growing season or when salts build up to high levels. Croplands can eventually become completely unproductive by a buildup of salts in the soil and in the shallow ground water.

<u>Location of shallow ground water</u>. In the study area, the land area underlain by a water table 0 to 5 feet below the land surface increased from 537,000 acres in the year 1977 to 847,000 acres in 1987. Figure 2-1 shows the lands affected in 1987 as well as lands where the ground-water levels are between 5 to 10 and 10 to 20 feet below the land surface. These additional

lands could be adversely affected as the water table continues to rise and the areal extent of shallow ground water continues to expand.

Establishing a water budget. The SJVDP has developed computerized water budgets to account for the water entering and leaving the semiconfined aquifer of each subarea. The purpose of these budgets is to determine the volumes of water (and dissolved substances) that must be controlled or managed if drainage problems are to be solved. The factors considered in this water budget are shown in Figure 2-2.

When the water entering a ground-water system is equal to the water leaving, the system is considered to be in hydrologic balance. If more water enters than leaves a system, ground-water storage increases and the water table rises. The reverse is true if more water leaves the system than enters it. Estimated annual changes in ground-water storage and table are shown in Table 2-1.

Table 2-1

ESTIMATED CURRENT ANNUAL CHANGE IN
GROUND-WATER STORAGE AND SHALLOW WATER TABLE

	Subarea				
	Northern	Grasslands	Westlands	Tulare	Kern
Change in storage (acre-feet/year)	0	+6,000	+95,000	+56,000	+162,000
Change in water table (feet/year)	0	+0.02	+1.2	+0.9	+1.0

Note: Assumes specific yield of 10%.

Source: SJVDP (estimates) and CH2M Hill (1988).

It is estimated that the water table in the Northern Subarea has stabilized and will remain at its present high levels if hydrologic conditions

FIGURE 2-1

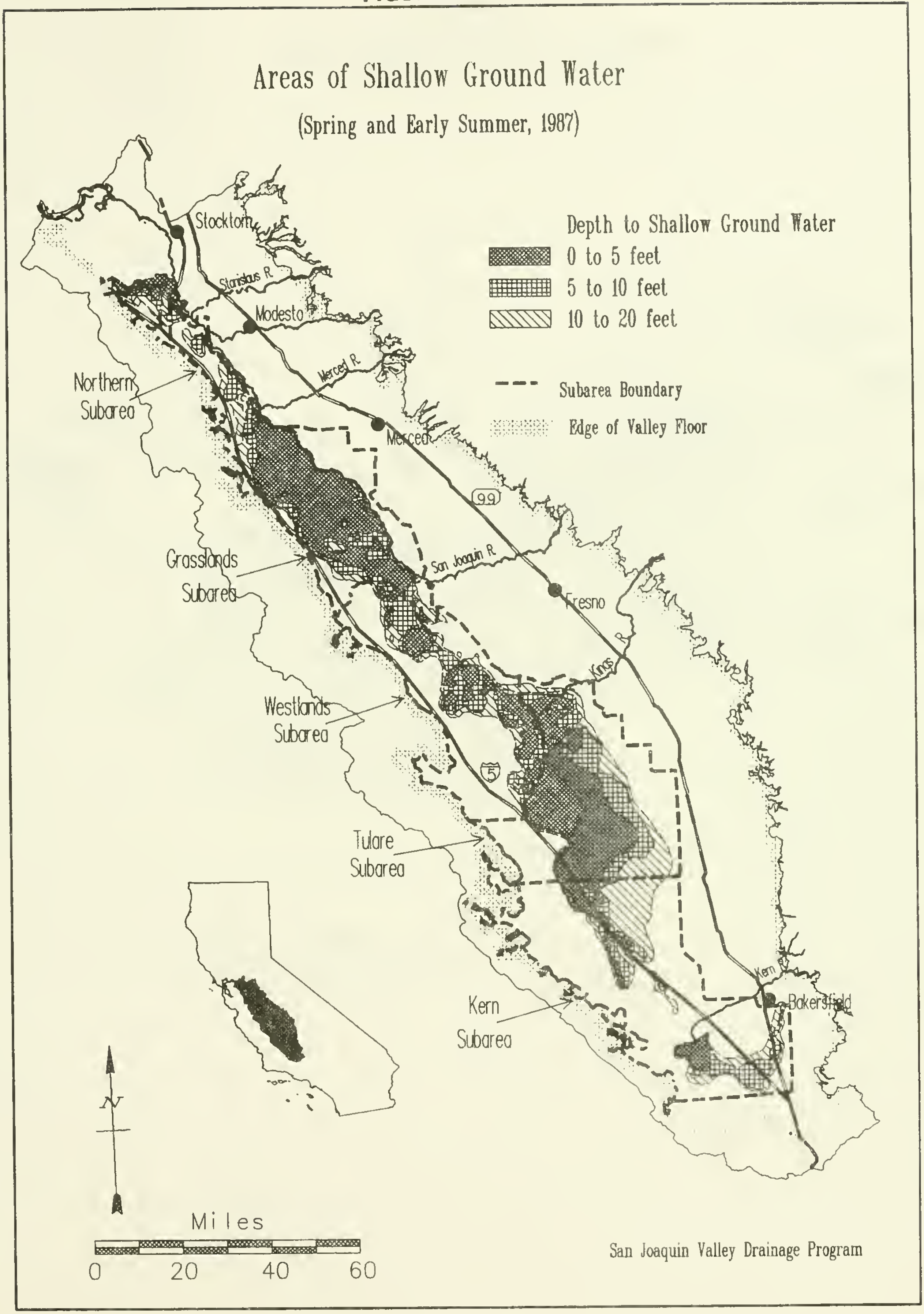
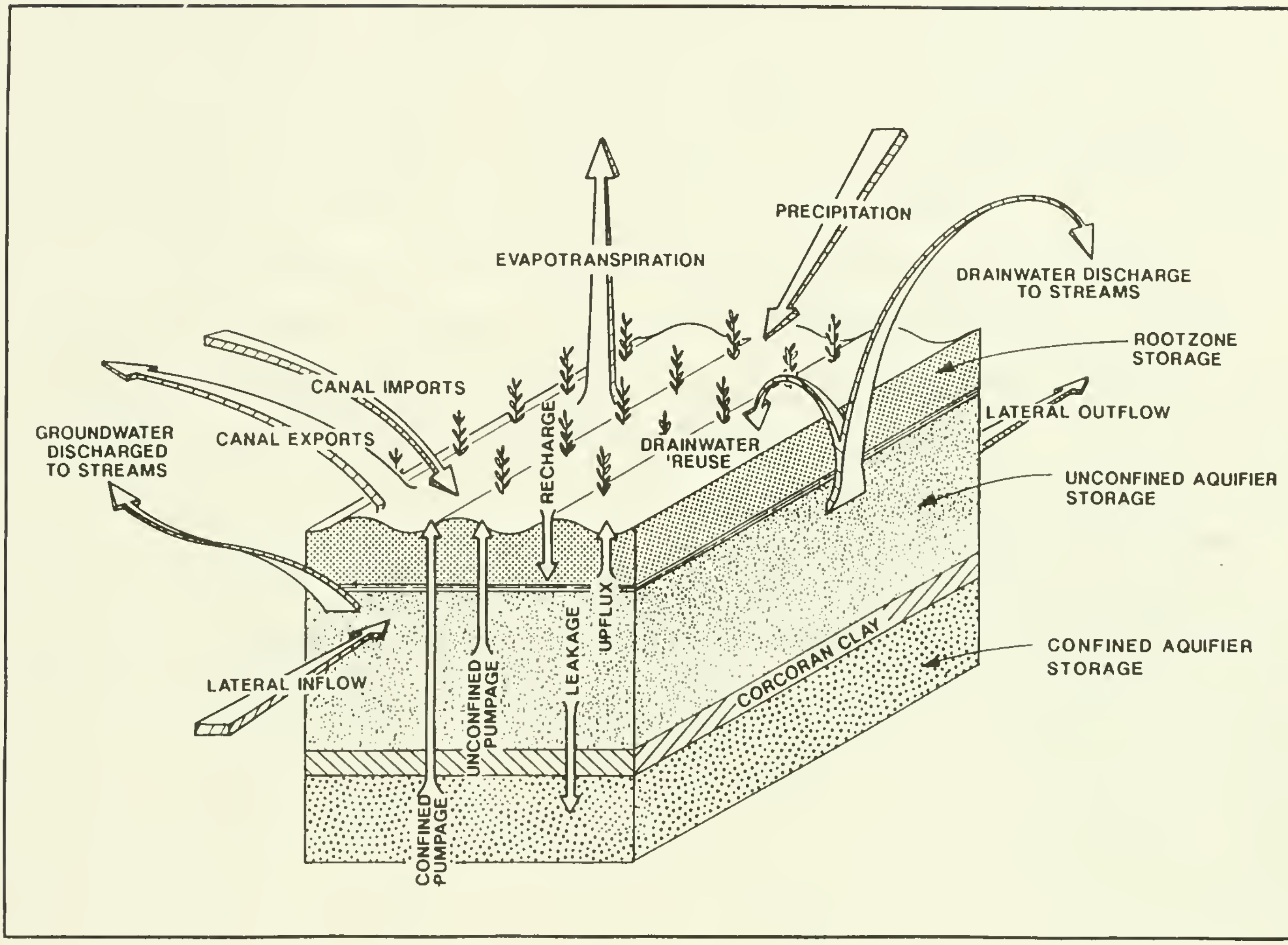

Areas of Shallow Ground Water
(Spring and Early Summer, 1987)
Depth to Shallow Ground Water
0 to 5 feet
5 to 10 feet
10 to 20 feet
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
Kern R.
Bakersfield
5
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
San Joaquin Valley Drainage Program

FIGURE 2-2

Conceptual Water Budget



Adapted from: CH2M Hill, October 1988, "San Joaquin Valley Hydrologic and Salt Load Budgets."

do not change. In the Grasslands Subarea, the system is approaching hydrologic balance. Although the water table appears to have stabilized in these two subareas, drainage is still required to alleviate shallow ground-water levels and to prevent root-zone waterlogging and salinization. Shallow ground water is especially a problem in parts of the Grasslands Subarea where it contains high concentrations of salts, boron, and selenium.

In the Westlands, Tulare, and Kern Subareas, significant changes in irrigation and water management practices will be required to achieve hydrologic balance. There is presently a net increase in water in these subarea systems, causing water tables to rise.

Estimates of the future rise in water-table elevations were based on results of water-budget analyses. Forecasts of the increase from 1987 to 2000 in affected land area, assuming no major change from present practices and trends, are shown in Table 2-2.

Table 2-2

ESTIMATED LAND AREA HAVING A
GROUND-WATER TABLE WITHIN 5 FEET OF LAND SURFACE
(ACRES)

Subarea	Year 1987	Year 2000	Assumptions for Year 2000 Estimates
Northern	51,000[a]	51,000[a]	1987 equilibrium maintained.
Grasslands	308,000[b]	308,000[b]	1987 equilibrium maintained.
Westlands	104,000	169,000	Some tile drain installation.
Tulare	320,000	366,000	Equilibrium attained in 2000.
Kern	64,000	100,000	Some tile drain installation.
TOTAL	847,000	994,000	

[a] Includes 26,000 acres of drained land.
[b] Includes 90,000 acres of wetland habitat.

Source: SJVDP, based on DWR and CH2M Hill data.

Estimate of problem water. From observed experience and results of geochemical investigations, it can be assumed that water in the 0- to 5-foot depth zone under agricultural land has the potential to become a drainage problem. It is assumed that the magnitude of the potential drainage problem, on an annual basis, is the volume of applied water that becomes deep percolation. The mean deep percolation for the study area is 0.75 acre-foot/acre. Therefore, the potential problem water for the study area in year 1987 is calculated as follows:

847,000 - 90,000 (wetlands) acres X 0.75 acre-ft/acre = 568,000 acre-ft.

By the same method, the potential problem water for the year 2000 is 682,000 acre-ft.

Except as a general index, however, this report does not specifically address potential problem water. Rather, the target for planning (demonstrated in Chapter 4) comprises that part of the potential problem water which--because of water-quality characteristics--will require control and management by the year 2000. Basically, it is water having salinity above 3,200 ppm (measured as TDS), and/or boron above 8 ppm, and/or selenium above 5 ppb. Defined in this way, problem water in the study area comprises approximately 300,000 acre-feet underlying more than 400,000 acres of irrigated land.

Contribution to deep percolation. A recent study has provided important information about the major sources of deep percolation. Burt and Katen (1988) reported on a pilot program conducted by DWR's Office of Water Conservation in association with the Westside Resource Conservation District. This program evaluated irrigation performance on 83 fields in western Fresno County and included assessment of past irrigation performance, preirrigation, regular irrigation, and annual performance. The following major conclusions are from the study report.

- Deep percolation will always occur in irrigation systems unless the complete field is underirrigated. Even with superb management and the most sophisticated irrigation systems, the primary cause of deep percolation will be inherent nonuniformity of application (called "distribution uniformity") rather than leaching required for maintaining a salt balance. Nonuniformity occurs with all irrigation methods.
- There is a wide range of irrigation efficiencies, deep percolation losses, etc., regardless of the method of irrigation, crop type, or soil type. The single, most important factor in determining

irrigation system performance is individual grower motivation due to economics, awareness, and/or abilities.

- o Hand-move sprinklers may be an interim solution to easily (not necessarily economically) obtain reasonably good distribution uniformities if a present furrow irrigation system has very bad performance. However, in order to achieve a very high annual performance standard, hand-move sprinklers are not an acceptable option.
- o Mean (weighted by acreage) values of annual performance are:

Irrigation efficiency	66%
Distribution uniformity	71%
Deep percolation	0.8 acre-foot/acre
Irrigation water applied	2.5 acre-feet/acre

- o One-third of the irrigation water applied percolated below the root zone (i.e., was deep percolation).
- o A high irrigation efficiency without underirrigation is approximately 80 percent. Assuming a 3-percent evaporation loss, no underirrigation, and good timing, universal achievement of 80 percent irrigation efficiency would result in about 0.4 acre-foot/acre of deep percolation.
- o Many fields have both underirrigation and deep percolation. This may occur during one irrigation (due to nonuniformity), and/or may occur between irrigations. For example, tomatoes may receive excessive deep percolation during preirrigation and later be underirrigated during the summer.

Salinity

The term "salinity" refers to the dissolved or precipitated mineral substances, or "salts," which are contained in soil or water. These substances include chlorides, sulfates, carbonates, and bicarbonates of the elements sodium, calcium, magnesium, and potassium. For water, salinity is typically reported in terms of total dissolved solids (TDS) or in electrical-conductivity (EC).

As the discussion of shallow ground water indicates, agricultural productivity can be adversely affected by a buildup of salts in the soil, if those salts persist in the root zone of crops. There are two sources of salts in the San Joaquin Valley: (1) Imported water, and (2) the soils and ground water. At the time of irrigation development, the arid soils of the west side contained substantial amounts of salts. Some of these salts have been leached below the root zone and are now dissolved in the ground water. As the water table rises, these salts are brought back near the surface where the water evaporates, leaving the salts behind. Another major source of salts is irrigation water, including supplies imported from the Delta and valley ground water.

Some crops are much more sensitive to salt than others. Crops such as vegetables, fruits, and nuts are sensitive and cannot be grown successfully in some parts of the valley because of elevated salt levels in the soil. Crops such as grains, cotton, or sugar beets are more salt-tolerant, and plants such as eucalyptus trees and saltbush (atriplex) can tolerate very high levels of salinity. Table 2-3 shows the salt tolerance of selected crops grown in the study area.

Salinity in shallow ground water. Figure 2-3 shows the salinity of shallow ground water in the study area, reported in units of electrical

Table 2-3

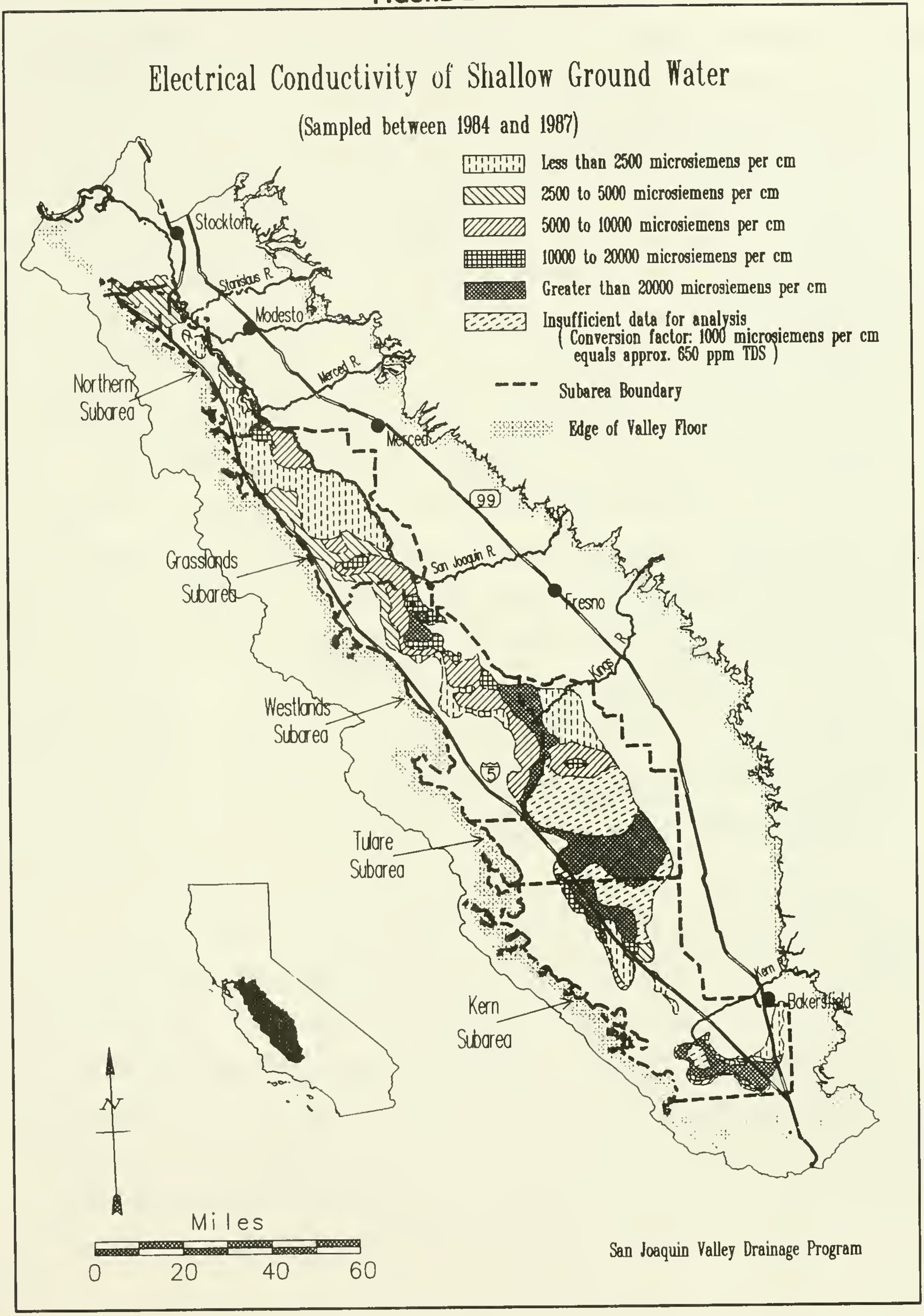
QUALITATIVE SALT TOLERANCE OF SELECTED CROPS

Crop	Qualitative Salt Tolerance Rating*
Alfalfa	MS
Almond	S
Apricot	S
Barley	T
Bean	S
Broccoli	MS
Cabbage	MS
Corn	MS
Carrot	S
Cotton	T
Cucumber	MS
Grape	MS
Lettuce	MS
Onion	S
Pepper	MS
Potato	MS
Safflower	T
Sorghum	MT
Spinach	MS
Sugar beet	T
Tomato	MS
Wheat	MT

*S = sensitive
MS = moderately sensitive
T = tolerant
MT = moderately tolerant

Source: Ayars and Westcot (1985).

FIGURE 2-3


Electrical Conductivity of Shallow Ground Water
(Sampled between 1984 and 1987)
Less than 2500 microsiemens per cm
2500 to 5000 microsiemens per cm
5000 to 10000 microsiemens per cm
10000 to 20000 microsiemens per cm
Greater than 20000 microsiemens per cm
Insufficient data for analysis
(Conversion factor: 1000 microsiemens per cm equals approx. 650 ppm TDS)
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
5
Kern R.
Bakersfield
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
San Joaquin Valley Drainage Program

conductivity. Water with salinity concentrations below 3,000 us/cm EC (about 2,000 ppm TDS) can be reused for irrigation with present management practices. Successful agricultural reuse of water that contains in excess of 4,500 us/cm EC (about 3,000 ppm TDS) has been demonstrated in research trials in the Tulare Basin and the Imperial Valley.

Elevated salt concentrations have not been shown to be directly toxic to aquatic birds, but ducks using a highly saline evaporation pond were killed by becoming so coated with salt that they could not fly (D. Barnum, June 2, 1989, comments before the CVRWQCB, Visalia, California).

Establishing a salt budget. In order to forecast future salinity conditions in the study area, a "salt budget" was prepared for the semiconfined aquifer using the same procedure used for the water budget. The major sources of salt "inflow" in the budget are (1) salts dissolved from the soil and (2) salts brought in with irrigation water (both surface water and ground water). In the budget calculations, salts are removed from the semiconfined aquifer by: (1) Ground-water pumping, (2) ground-water discharge to streams, (3) on-farm drainage (eventually discharged to streams or to evaporation ponds), and (4) vertical flow between the semiconfined and confined aquifers.

Estimate of salt accumulation. The salt budget shows the annual salt accumulation in the study area to be approximately 3,308,000 tons. Figure 2-4 shows the salt load overall and for the individual subareas.

Accumulated salts from the Westlands, Tulare, and Kern Subareas are presently retained entirely in ground water, soils, and evaporation ponds. These subareas lie wholly or partly within the hydrologically closed Tulare Basin. Most of the salt inflows to the Northern and Grasslands Subareas are transported from the subareas through the San Joaquin River and its

tributaries. The continued availability of the San Joaquin River to receive and convey present quantities of salts could change. The Central Valley Regional Water Quality Control Board (CVRWQCB) is currently considering water-quality objectives which, especially in dry years, might result in a reduction in the amount of saline drainage water that could be discharged to the river.

Substances of Concern

The phrase "substances of concern" is widely used to describe a group of toxic or potentially toxic elements or other chemical constituents, some of which may be present in agricultural drainage water. The principal source of many of these substances is the geologic formations of the Coast Ranges; thus, the substances occur naturally in west-side soils. Irrigation, evapotranspiration, and drainage of these soils have mobilized, transported, and concentrated these substances in shallow ground water, evaporation ponds, and local surface waters, where they are bioavailable. Other minor sources include the irrigation water itself and possibly agrichemicals.

In recent years the ability to accurately measure very low concentrations of trace elements in the environment has provided much information about the concentrations, sources, and distribution of those which are substances of concern. Basically, the substances are of concern in the environment because of actual or possible adverse effects on water quality, public health, agricultural productivity, and/or fish and wildlife.

A list of potential and known substances of concern was evaluated by a group of scientists in 1987 acting as an advisory committee to the SJVDP. These substances were categorized as shown in Table 2-4. Program efforts focus on substances of primary concern.

Criteria used by the SJVDP as evidence of "primary concern" include: (1) The substance has been cited in State/Federal water-quality

FIGURE 2-4

ANNUAL SALT BUDGET FOR THE SEMICONFINED AQUIFER

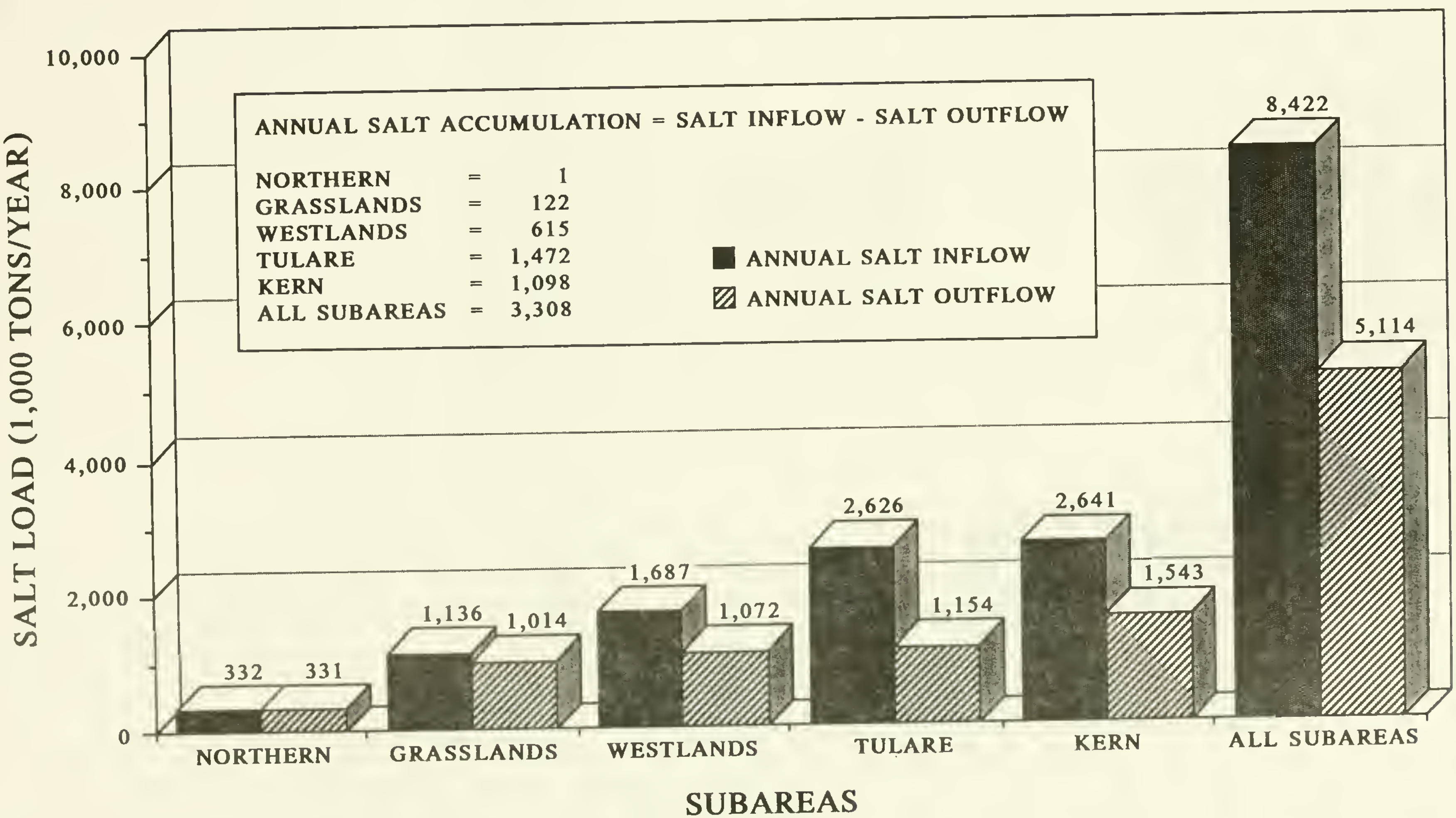


Table 2-4

SUBSTANCES OF CONCERN

Primary Concern	Probable Concern[a]	Possible Concern
Selenium	Cadmium	Uranium[b]
Boron	Chromium	Vanadium[b]
Molybdenum	Copper	Nitrates[b]
Arsenic	Manganese	Tellurium[c]
Salts	Nickel	Mercury[d]
	Zinc	Antimony[c]
		Lithium[c]
		Germanium[c]
		Bismuth[c]
		Strontium[c]
		Fluoride[c]
		Beryllium[c]

Limited Concern[d]	Probably Not of Concern at Present Time
Lead	Magnesium
Silver	Iron
	Barium
	Aluminum

---

[a] Subject to California water-quality objectives in the future.
[b] Elevated concentrations have been observed in some locations.
[c] Very little information available.
[d] Known toxic elements but found in low concentrations.

regulations (i.e., there are water-quality criteria affecting its concentration, use, and distribution), (2) it is known to cause toxicity and create other problems for aquatic life, and (3) it can become hazardous to other wildlife and humans by bioaccumulation and biomagnification through the food chain or by direct exposure to contaminated soils, sediments, air, or ground waters and surface waters.

The trace elements of primary concern are selenium, boron, molybdenum, and arsenic, all of which occur naturally in west-side soils. In addition, the SWRCB and SJVDP have identified "salts" as being of primary concern. Arsenic is of primary concern in certain local areas primarily in the Tulare and Kern Subareas. Recent studies indicate that in certain areas such as parts of Westlands Water District, concentrations of chromium (as Cr^{+6}) have been observed above background levels. Hence, additional as well as more intensive investigations are under way with the probable result that chromium will be added to the SJVDP's list of elements of primary concern.

In addition, other elements for which the SWRCB eventually may establish site-specific water-quality criteria are cadmium, copper, manganese, nickel, and zinc. Recent studies on evaporation ponds have shown high concentrations of uranium in some samples. Correlated with this are some elevated concentrations of vanadium in these evaporation ponds. Other elements have been measured in ongoing monitoring programs and include nitrates, tellurium, mercury, antimony, germanium, bismuth, strontium, fluoride, beryllium, lead, magnesium, iron, aluminum, lithium, silver, and barium. There is not enough information on the effect of some of these elements to establish them as being of primary concern, or the concentrations are not high enough to establish a definite level of concern.

In addition to trace elements, pesticides may pose a risk to public health and the environment. Although pesticides have rarely been detected above trace levels in subsurface drainage water, they have been observed at measurable levels in agricultural tailwater (field runoff). Commingling of tailwater and subsurface water is a common practice in portions of the San Joaquin Basin and in many areas in the Tulare Basin. Commingled water that is or could become a problem because of pesticides or other organic contaminants is included in SJVDP investigations.

Selenium and Other Potentially Toxic Trace Elements

The trace elements of primary concern are: selenium, boron, molybdenum, and arsenic, all of which occur naturally in west-side soils. There are good correlations between the occurrence of selenium, boron, and molybdenum, but not between arsenic and the other substances of primary concern.

Selenium. In most parts of the study area, selenium is the element of greatest concern because of its wide distribution and proven and potential toxicity. As a result, much research has focused on the sources, distribution, and mobility of selenium in soils and ground water of the western and southern San Joaquin Valley. Additional studies are providing information about the sources and concentrations of selenium in the San Joaquin River, which receives subsurface drainage water from about 77,000 acres of irrigated land (SWRCB, 1987).

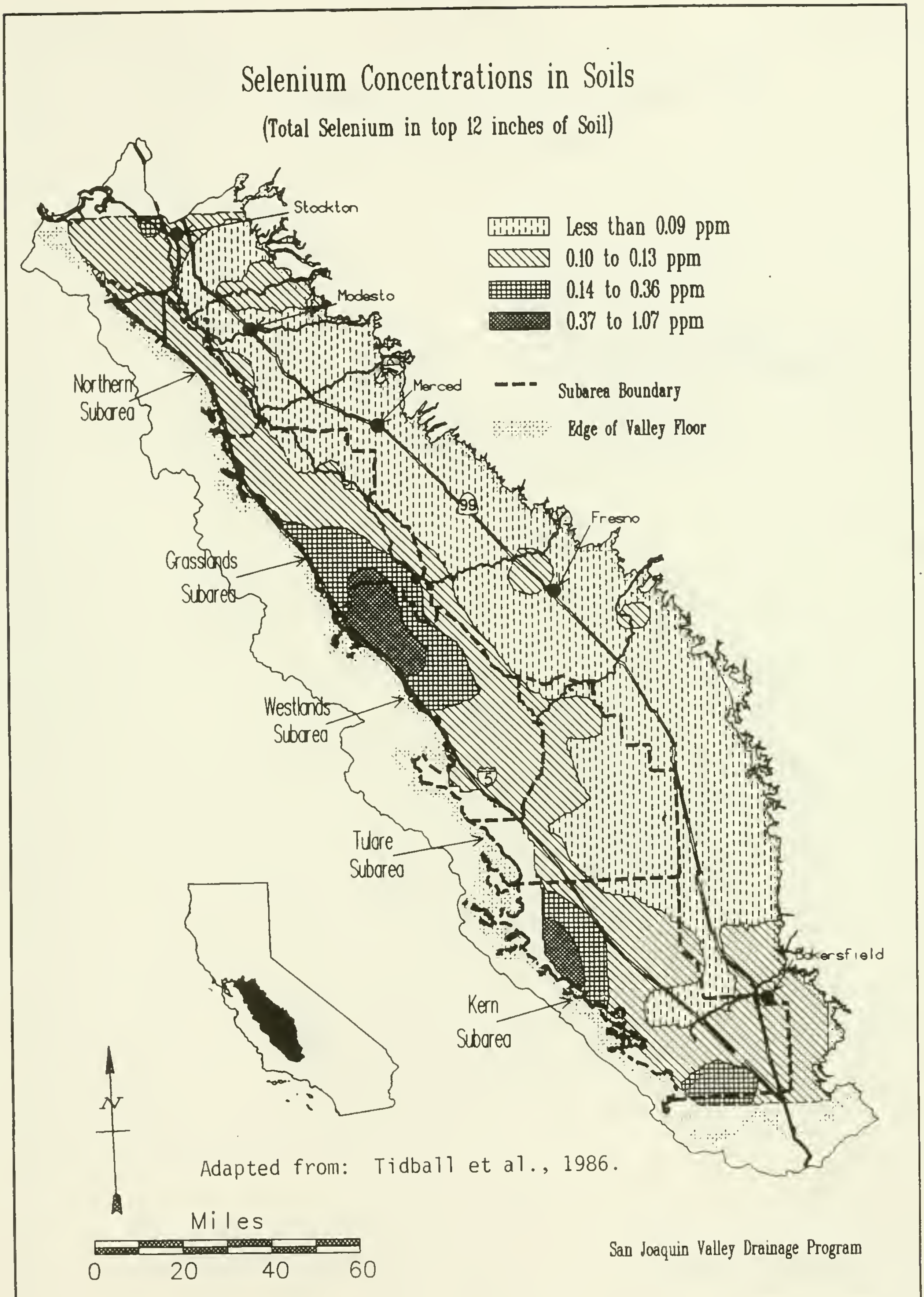
Geologic sources of selenium and its distribution in soil--Selenium in soils of the San Joaquin Valley originates from geologic formations in the Coast Ranges. Water and mudflows have transported the selenium to the valley in particulate and dissolved forms derived from the weathering and erosion of source rocks.

The distribution of total selenium in the top 12 inches of soil was assessed and mapped for the entire valley and is shown in Figure 2-5. Only slightly more than 10 percent of valley soils have present-day concentrations of selenium greater than the national median of 0.3 ppm (Tidball et al., 1986). Virtually all concentrations greater than the valley median of 0.13 ppm occur in alluvial-fan material derived from weathering and erosion of Coast Range rocks. In these areas, selenium concentrations in soils are as high as 4.5 ppm. The highest present-day concentrations of selenium in soils are generally found in areas between the alluvial fans, within a few miles of the Coast Ranges. These "interfan" areas are among the more recently irrigated areas.

Selenium in shallow ground water--The highest concentrations of selenium in shallow ground water are generally located along the edge of the valley trough in the lower parts of the Coast Range alluvial fans. (See Figure 2-6.) These are the same areas that had the highest soil salinity prior to the development of irrigated agriculture. Decades of irrigation and drainage have systematically transferred soluble selenium from the upper soils into the shallow ground water. USGS studies, generally conducted in the Grasslands and Westlands Subareas, show that the deepest level at which ground water contains selenium at more than 10 ppb is at a depth of 148 feet (Gilliom et al., 1989).

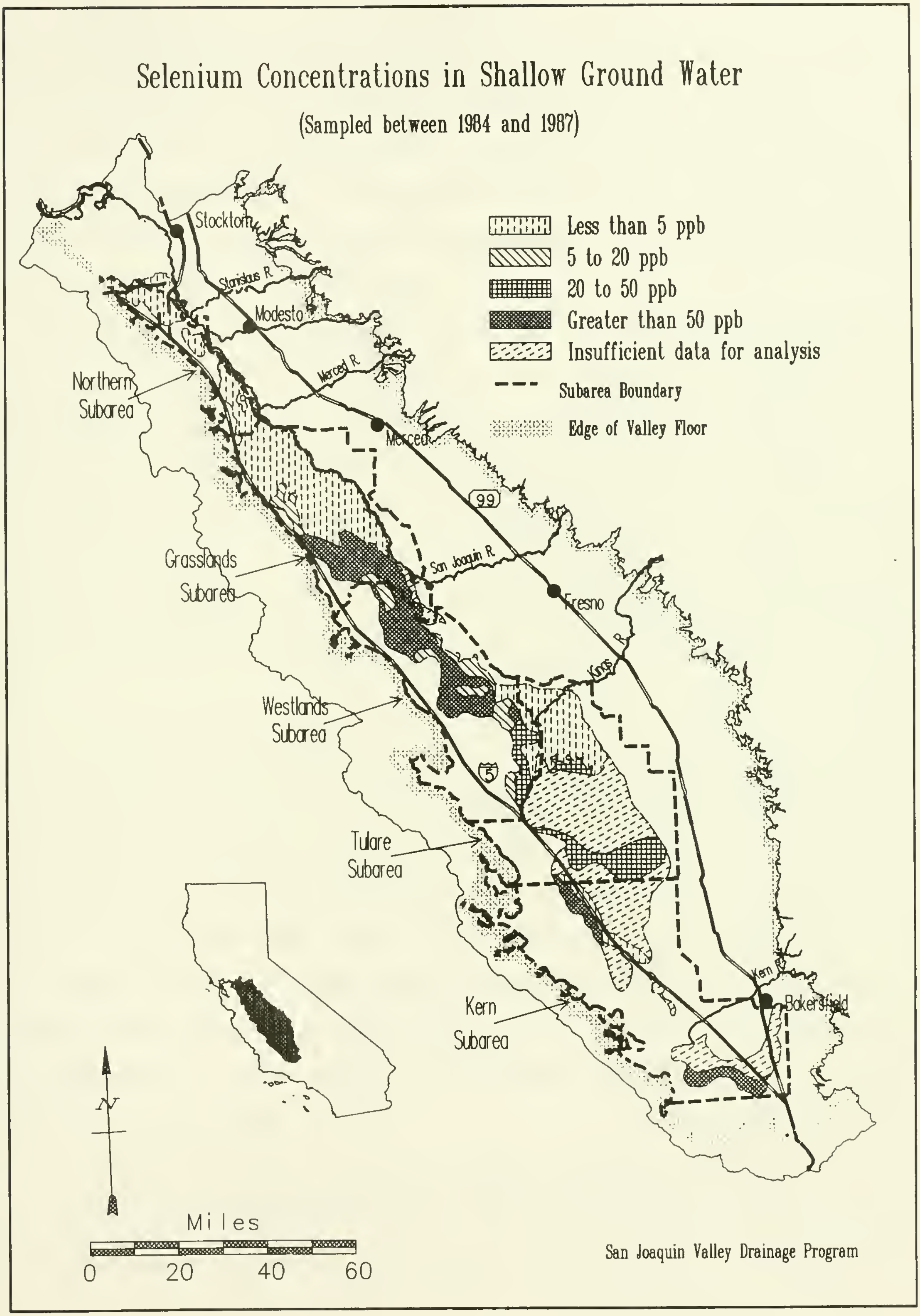
There are several chemical species of selenium, and they vary in solubility. The majority of the selenium on the west side is selenate (SeO_4^{-2}), which is highly soluble. Selenium solubility is highly dependent on the oxidation state of the water, or its redox potential, which determines the rate at which selenium may be oxidized from the selenite (SeO_3^{-2}) or selenide (HS_e^{-1}) form to selenate. Ground-water redox

FIGURE 2-5



Selenium Concentrations in Soils
(Total Selenium in top 12 inches of Soil)
Less than 0.09 ppm
0.10 to 0.13 ppm
0.14 to 0.36 ppm
0.37 to 1.07 ppm
Subarea Boundary
Edge of Valley Floor
Stockton
Modesto
Merced
Fresno
Bakersfield
99
5
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Adapted from: Tidball et al., 1986.
Miles
0
20
40
60
San Joaquin Valley Drainage Program

FIGURE 2-6



Selenium Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Less than 5 ppb
5 to 20 ppb
20 to 50 ppb
Greater than 50 ppb
Insufficient data for analysis
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
5
Kern
Bakersfield
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
San Joaquin Valley Drainage Program

conditions range from oxidizing in upper parts of the Coast Range alluvium on the west side of the valley, to reducing in ground water in Sierra Nevada sediments on the east side of the valley. The absence of selenium in ground water of Sierran deposits and in the confined aquifer below the Corcoran Clay may be due to the low oxidation state of these waters. Sierran geologic rocks and soils are generally low in selenium.

Selenium concentrations are correlated directly with the dissolved-solids content, or salinity, of shallow ground water in the western San Joaquin Valley (Dubrovsky and Deverel, 1989). This relationship is the result of evaporative concentration and leaching. Most dissolved solids, including trace elements, now in shallow ground water were leached from naturally saline soils by irrigation water. According to studies by the USGS, a majority of the most readily soluble forms of selenium were leached from the soil into the ground water during the first few decades of irrigation (Gilliom et al., 1989).

In areas where the water table is less than 5 feet below the land surface, evaporative concentration of dissolved solids in ground water can increase significantly ground-water salinity and selenium concentrations far above the levels resulting from leaching. Under predevelopment conditions, when little recharge of ground water occurred through the lower fan soils, ground-water discharge and evapotranspiration at lower elevations (e.g., in the valley trough) resulted in accumulation of salts in the soil rather than in the ground water. Under irrigation development, soils are regularly leached by percolating water.

<u>Sources and concentrations of selenium in the San Joaquin River</u>--Approximately 200,000 acre-feet of ground water per year flows into the San Joaquin River through Salt and Mud Sloughs in the form of direct ground-

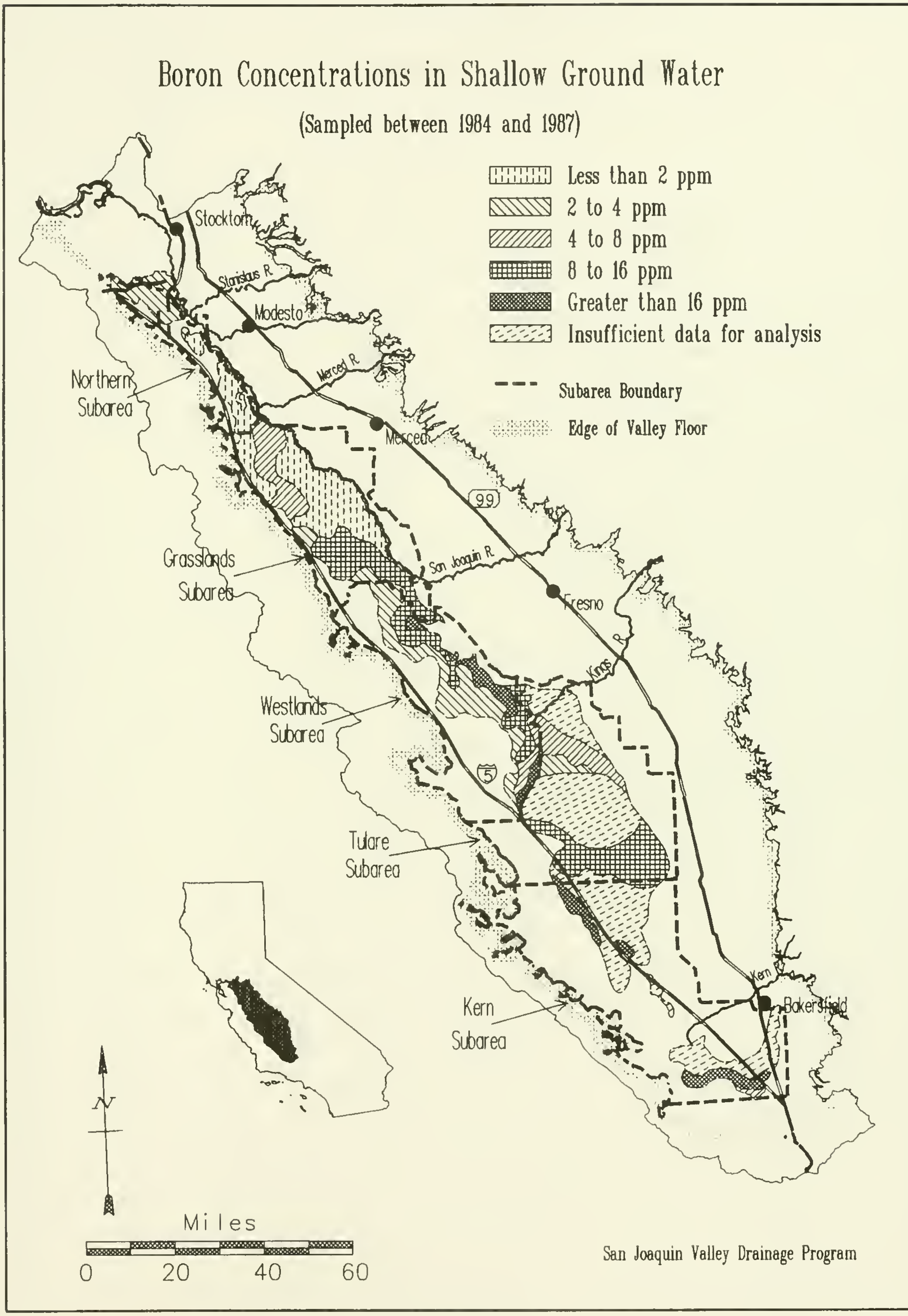
water seepage (about 130,000 acre-feet) and discharges of drainage water (about 70,000 acre-feet). Only about 10,000 acre-feet of the ground-water seepage into the river has elevated selenium concentrations, but about 46,000 acre-feet of subsurface drainage water has elevated selenium concentrations. During low-flow periods, Salt and Mud Sloughs contribute about 9 percent of the total flow at Vernalis, but they contribute about 80 percent of the total selenium load (Pickett and Kratzer, 1988).

Water in the San Joaquin River downstream from the sloughs exceeds proposed selenium standards for protection of aquatic life (5 ppb) more than 40 percent of the time. Water in the sloughs exceeds 5 ppb more than 60 percent of the time.

Public health implications of elevated selenium--Selenium is a required nutrient for humans, yet is known to cause toxicity in relatively small concentrations. Deficiency and toxicity syndromes have been found in animals and humans in regions of the world where natural soil or water levels are very low (Chen et al., 1980) or unusually high (Anon., 1962; Franke, 1934; Yang et al., 1983), respectively. Symptoms of chronic exposure to elevated dietary selenium include gastrointestinal disturbances, nail and hair loss, listlessness, and numerous neurological signs. (See Klasing and Pilch, 1988, for a complete discussion.)

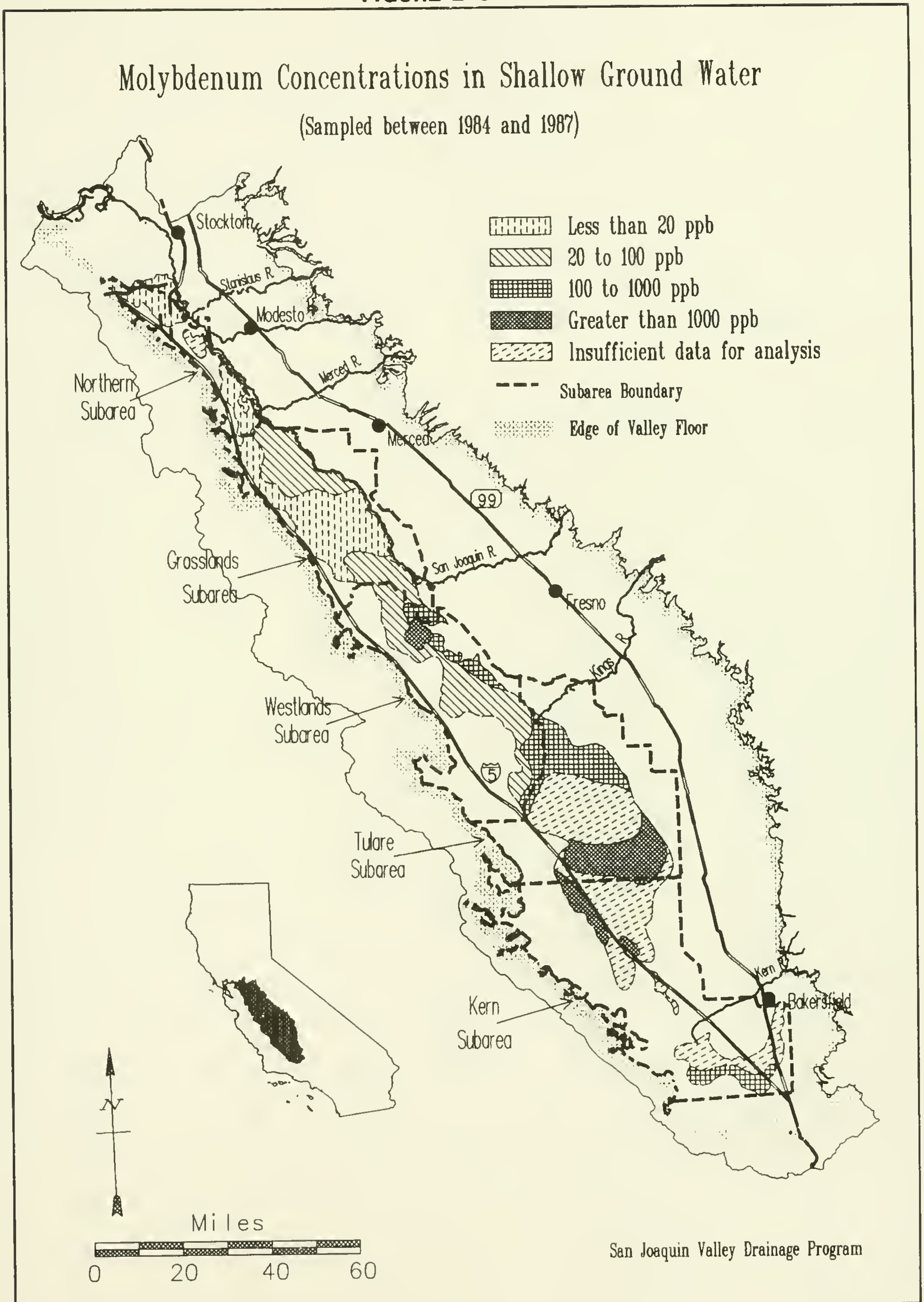
Other trace elements in ground water and drainage water. Besides selenium, the study of other trace elements has centered on boron, molybdenum, and arsenic. Distribution of these three elements in shallow ground water is shown in Figures 2-7, 2-8, and 2-9. These figures show that elevated concentrations of boron (less than 2 ppm) in ground water are found in parts of all subareas, except the Northern Subarea. Elevated concentrations of

FIGURE 2-7



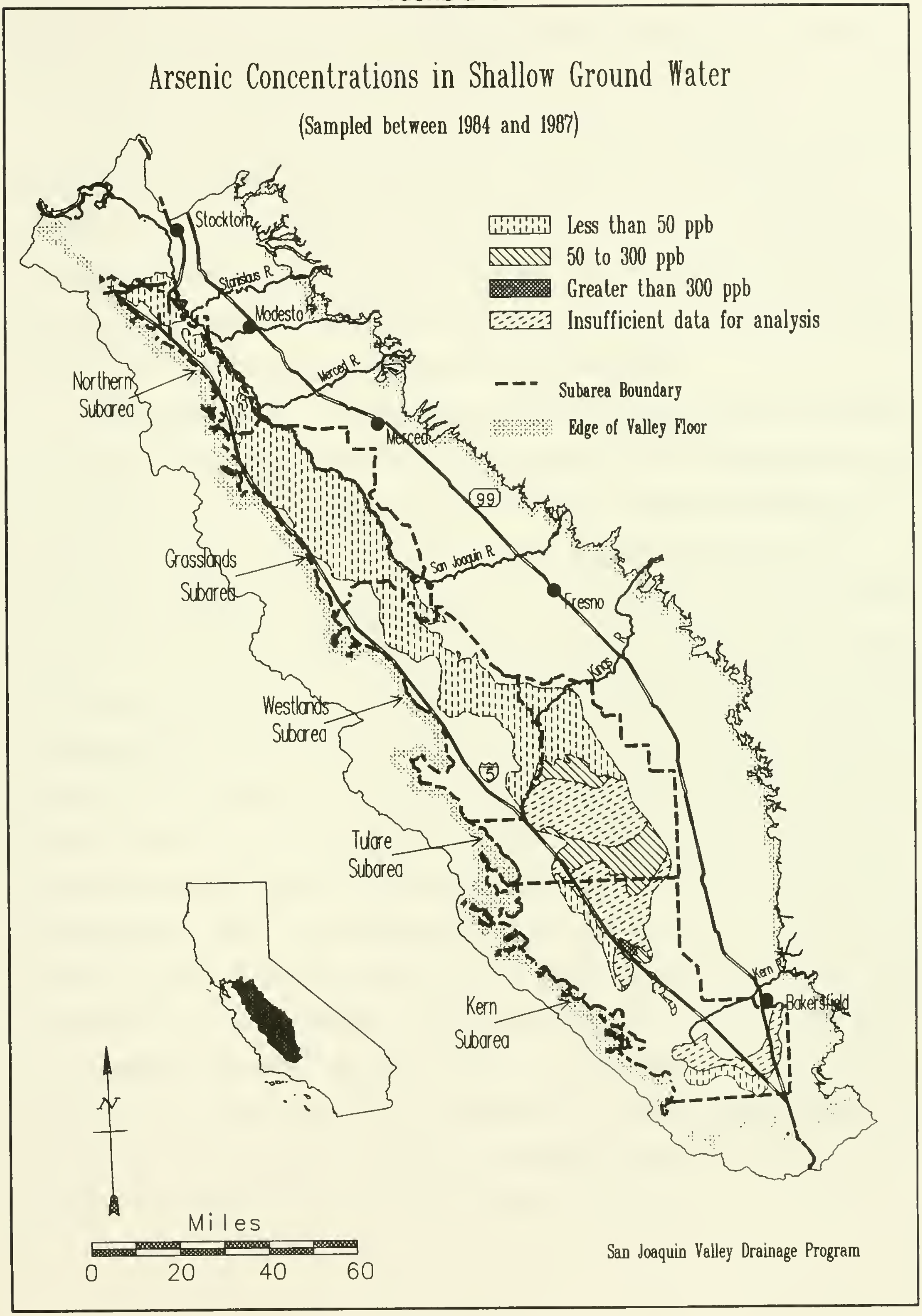
Boron Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Less than 2 ppm
2 to 4 ppm
4 to 8 ppm
8 to 16 ppm
Greater than 16 ppm
Insufficient data for analysis
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
Kern R.
Bakersfield
5
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0 20 40 60
San Joaquin Valley Drainage Program

FIGURE 2-8



Molybdenum Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Less than 20 ppb
20 to 100 ppb
100 to 1000 ppb
Greater than 1000 ppb
Insufficient data for analysis
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
5
Kern R.
Bakersfield
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
San Joaquin Valley Drainage Program

FIGURE 2-9



Arsenic Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Less than 50 ppb
50 to 300 ppb
Greater than 300 ppb
Insufficient data for analysis
Subarea Boundary
Edge of Valley Floor
Stockton
Stanislaus R.
Modesto
Merced R.
Merced
99
San Joaquin R.
Fresno
Kings R.
5
Kern R.
Bakersfield
Northern Subarea
Grasslands Subarea
Westlands Subarea
Tulare Subarea
Kern Subarea
N
Miles
0
20
40
60
San Joaquin Valley Drainage Program

arsenic (less than 50 ppb) and molybdenum (less than 20 ppb) are found in the Tulare and Kern Subareas, primarily associated with old lakebeds.

Boron was regarded primarily as an agricultural crop problem until recent research by the USFWS showed damage to mallard ducklings at 900 ppm (dry weight) in the diet. Evaporation ponds receiving the highest concentrations of boron in drainage water contain food-chain organisms which have boron in the 400-900 ppm range. Definitive studies of the potential negative effects of high levels of environmental boron are not available.

Molybdenum toxicity in ruminant animals (principally cattle and sheep) grazing on lands containing naturally high levels of soil molybdenum has been documented in several countries (Ferguson et al., 1938; Cunningham et al., 1953; Dick, 1956), as well as the San Joaquin Valley (Barshad, 1948). Molybdenum toxicity occurs more readily in ruminant than nonruminant animals and may follow consumption of forage with molybdenum concentrations of 15 to 300 ppm (dry weight) (Dick, 1956). Some molybdenum concentrations observed in drainage water in the Tulare Basin may exceed threshold levels for stock watering and irrigation of forage crops; however, molybdenum concentrations of local forage crops are not available. The biological impacts on waterfowl using evaporation ponds with high concentration of molybdenum are unknown. Symptoms associated with molybdenum toxicity also have been reported in humans living in areas of Russia and India where local foods have contained naturally elevated levels of molybdenum. Additionally, exposure to 540 micrograms/day of molybdenum in humans has been shown to result in cooper depletion (the major toxic response to excessive molybdenum). (See Klasing and Pilch, 1988, for full discussion and references.) Molybdenum concentrations in valley crops are not known, but are being assessed by the SJVDP.

Certain chemical forms of inorganic arsenic are suspected human carcinogens. Naturally elevated concentrations of arsenic in water are reported to have caused human illness in several areas of the world (Chen et al., 1988; Zaldivar, 1980). The current maximum contaminant level for arsenic compounds in drinking water is 50 ppb (USEPA, 1985). The EPA freshwater aquatic water-quality criteria for chronic exposure to trivalent arsenic is 190 ppb. The significance of total dissolved arsenic concentrations exceeding this level in the evaporation pond environment is not known.

Trace elements in evaporation ponds. Evaporation ponds are one of the two most common means to dispose of subsurface drainage water in the San Joaquin Valley. In the San Joaquin Basin, drainage water is usually discharged directly to surface ditches, canals, streams, and sloughs, eventually reaching the San Joaquin River. Because the Tulare Basin lacks a surface-water outlet in most years, the use of evaporation ponds to dispose of drainage water is particularly important in the Tulare and Kern Subareas. Numerous evaporation ponds have been constructed there, and to date drainage waters have been routinely discharged at full strength (without treatment or dilution) into these large, open ponds.

The same evaporation process which concentrates salts also often leads to high concentrations of actually and potentially toxic elements. Although the ponds are highly saline, the aquatic-bird food productivity of evaporation ponds enhances their attractiveness for many species of wildlife. Aquatic migratory birds of the Pacific Flyway (such as waterfowl, shorebirds, and wading birds), which historically used the extensive wetlands, lakes, and rivers in the valley, find the ponds especially attractive. The ponds draw migratory birds, in part, because almost all of the native aquatic and wetland habitats in the valley (especially in the Tulare Basin) have disappeared with

development of the basin, and because the ponds are generally the only large water bodies in an agricultural landscape.

Evaporation ponds are shallow, warm, and nutrient enriched (Tribbey, 1988). Because the ponds are highly saline (sodium sulfate or sodium sulfate-chloride dominated salinity of pond waters ranges from 2,675 to 388,000 ppm TDS [Westcot et al., 1988a]), biological activity is limited in terms of species diversity (Tribbey and Beckingham, 1986). However, those few plant and animal species which can tolerate high salinity flourish in the absence of competition from other species. Production of many aquatic plants and animals that are important in the diet of aquatic birds is very high (Parker and Knight, 1989; Tribbey, 1988). Primary productivity in some evaporation ponds is several orders of magnitude higher than that found in most other aquatic systems (Tribbey, 1988).

Large numbers of wintering and some breeding waterfowl (almost exclusively ducks) feed on the abundant aquatic plant and invertebrate life produced in evaporation ponds. The most common species of ducks found using evaporation ponds include: cinnamon teal, gadwall, green-winged teal, mallard, northern pintail, northern shoveler, redhead, and ruddy duck (Hoffman-Floerke, 1985; Schroeder et al., 1988; Tribbey, 1988; Tribbey and Beckingham, 1986).

Large numbers of other aquatic birds, including American coot, American avocet, black-bellied plover, black-necked stilt, dunlin, eared grebe, great blue heron, greater yellowlegs, killdeer, least sandpiper, lesser yellowlegs, long-billed dowitcher, western sandpiper, western snowy plover, and Wilson's phalarope, are also common users of evaporation ponds (Hoffman-Floerke, 1985; Schroeder et al., 1988; Tribbey, 1988; Tribbey and Beckingham, 1986). Shorebirds nest in large numbers on levees and wavebreaks at many ponds and

feed along the shorelines (Roster et al., in press; Schroeder et al., 1988; Tribbey and Beckingham, 1986). Use of evaporation ponds by some aquatic birds (especially shorebirds) can exceed that of neighboring wildlife areas (Schroeder et al., 1988).

There are 27 known evaporation ponds in the San Joaquin Valley. Those ponds cover approximately 7,400 acres (Figure 2-10, Table 2-5). Field investigations have shown that, in several instances, concentrations of a number of trace elements in the ponds are highly elevated (Table 2-6).

Field studies of reproductive success and/or survival of young have been undertaken at 12 of the 27 evaporation pond systems (approximately 44 percent of the ponds representing approximately 75 percent of the total acreage of ponds in the valley). Statistically significant adverse biological effects have been documented at seven of those pond systems (representing approximately 58 percent of the total pond acreage in the valley). Statistically significant rates of impaired egg hatchability have been documented at all seven of those ponds, significantly elevated frequencies of embryo deformities have been detected at three ponds, and a colony of eared grebes at one pond experienced complete reproductive failure (Ohlendorf, 1988; Schroeder et al., 1988; Skorupa, 1989; Skorupa and Ohlendorf, 1989; Skorupa and Ohlendorf, 1988). Table 2-7 presents information on contamination of wildlife and their habitat and valley evaporation ponds.

Research indicates that the adverse biological effects documented at the ponds may have been caused by the individual or interactive toxicity of elevated concentrations of one or more of the trace elements of concern carried in subsurface agricultural drainage water. Westcot et al. (1988a) noted that arsenic, boron, molybdenum, and selenium occur at high

FIGURE 2-10

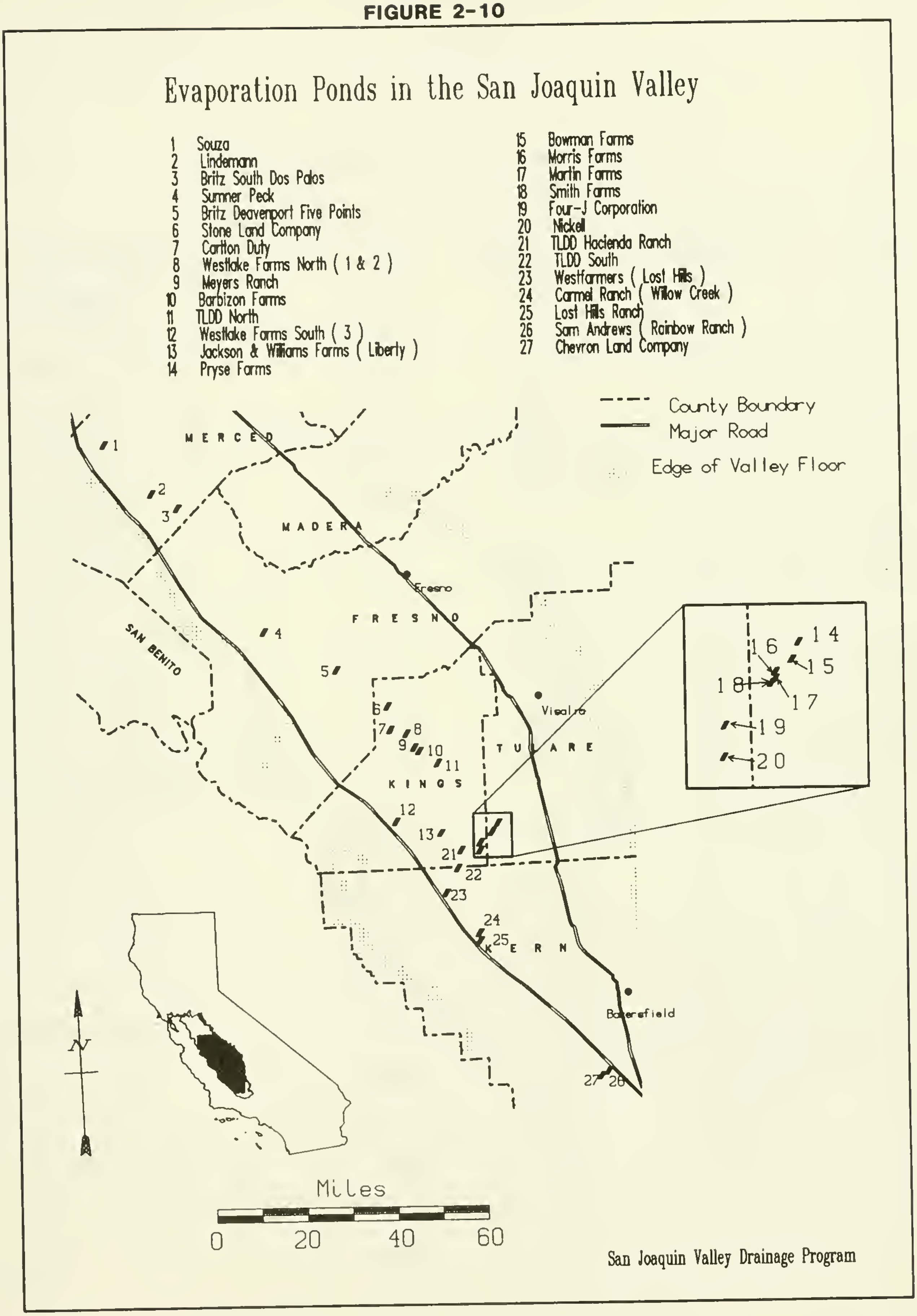

Evaporation Ponds in the San Joaquin Valley
1 Souza
2 Lindemann
3 Britz South Dos Palos
4 Sumner Peck
5 Britz Deavenport Five Points
6 Stone Land Company
7 Carlton Duty
8 Westlake Farms North (1 & 2)
9 Meyers Ranch
10 Barbizon Farms
11 TLDD North
12 Westlake Farms South (3)
13 Jackson & Williams Farms (Liberty)
14 Pryse Farms
15 Bowman Farms
16 Morris Farms
17 Martin Farms
18 Smith Farms
19 Four-J Corporation
20 Nickell
21 TLDD Hacienda Ranch
22 TLDD South
23 Westfarmers (Lost Hills)
24 Carmel Ranch (Willow Creek)
25 Lost Hills Ranch
26 Sam Andrews (Rainbow Ranch)
27 Chevron Land Company
County Boundary
Major Road
Edge of Valley Floor
MERCED
MADERA
FRESNO
SAN BENITO
KINGS
TULARE
KERN
Fresno
Visalia
Bakersfield
N
Miles
0 20 40 60
San Joaquin Valley Drainage Program

Table 2-5

EVAPORATION PONDS IN THE SAN JOAQUIN VALLEY[a]

Pond Name [Basin Number][b]	County[c]	First Year of Operation[c]	Present size (acres)[d]	Acres Drained[e]
Sam Andrews (aka Rainbow Ranch) [26]	Kern	1983	122	1,075
Barbizon Farms [10]	Kings	1985	102	700
Bowman Farms [15]	Tulare	1981	51	210
Britz South Dos Palos [3]	Merced	1985	42	320
Britz Deavenport Five Points [5]	Fresno	1982	30	240
Carmel Ranch (aka Willow Creek) [24]	Kern	1972	132	563
Chevron Land Company [27]	Kern	1985	57	---
Carlton Duty [7]	Kings	1983	390	609
Four - J Corporation [19]	Kings	1985	30	100
Jackson & Williams Farms (aka Liberty Farms) [13]	Kings	1981	627	7,040
Lindemann [2]	Merced	---	---	---
Lost Hills Ranch [25]	Kern	1981	92	790
Martin Farms [17]	Tulare	1985	17	120
Meyers Ranch [9]	Kings	1983	84	508
Morris Farms [16]	Tulare	1985	40	640
Nickell [20]	Kings	1985	15	170
Sumner Peck [4]	Fresno	1984	105	960
Pryse Farms [14]	Tulare	1985	83	670
Smith Farms [18]	Tulare	1985	8	---
Souza [1]	Merced	---	9	---

Table 2-5 (Cont'd)

EVAPORATION PONDS IN THE SAN JOAQUIN VALLEY[a]

Pond Name [Basin Number][b]	County[c]	First Year of Operation[c]	Present size (acres)[d]	Acres Drained[e]
Stone Land Company [6]	Kings	1984	213	2,134
Tulare Lake Drainage Dist. Hacienda Ranch [21]	Kings	1978	1,401	9,555
Tulare Lake Drainage Dist. North [11]	Kings	1974	294	2,180
Tulare Lake Drainage Dist. South [22]	Kings-Kern	1978	1,890	15,383
Westfarmers (aka Lost Hills) [23]	Kern	1984	546	8,000
Westlake Farms North (#1 & #2) [8]	Kings	1984	258	2,500
Westlake Farms South (#3) [12]	Kings	1984	812	1,920
Totals			7,448[f]	56,417

a Includes all 27 known evaporation ponds in the San Joaquin Valley. "---" indicates no data are available.
b Numbers in brackets are evaporation pond "basin numbers" assigned by the CCVRWQCB (Westcot et al., 1988a).
c Westcot et al., 1988.
d Acreage derived from computerized geographic information system digitized boundaries of evaporation ponds interpreted from aerial photographs taken May 1988. Acreage values are rounded off to the nearest whole number.
e Ford, 1988.
f Total is the rounded-off sum of GIS calculated acreages for each pond system (to two significant figures). Due to round off error associated with individual acreage values reported in the column, the total reported is not equal to the column total.

Table 2-6

MAXIMUM OBSERVED CONCENTRATIONS OF
TRACE ELEMENTS IN EVAPORATION PONDS

Pond	Arsenic (ppb)		Boron (ppb)		Molybdenum (ppb)		Selenium (ppb)	
	Inflow	Pond	Inflow	Pond	Inflow	Pond	Inflow	Pond
Souza	ND	ND	2.1	ND	7	ND	3.4	ND
Lindemann	ND	ND	ND	ND	ND	ND	ND	ND
Britz, So. D.P	4	2	8.1	12	114	250	5.1	6.6
Sumner Peck	4	5	9.5	34	83	420	943	1,900
Britz-Deavenport	3	10	30	76	325	650	93	83
Stone Land Co.	8	41	33	200	725	2,160	9.1	5.8
Carlton Duty	140	200	47	180	1,050	870	32	17
Westlake 1 & 2	33	<10	13	23	410	800	4.1	2.9
Meyers Ranch	20	8	3.5	11	300	700	1.5	1.6
Barbizon Farms	52	93	7.1	14	570	915	1.2	1.6
TLDD North	170	480	2.8	13	290	780	1.1	2.5
Westlake 3	65	120	29	41	700	850	25	16
Liberty Farms	11	17	22	120	1,500	3,600	42	38
Pryse Farms	330	1,200	18	75	1,900	6,400	13	17
Bowman Farms	240	80	19	23	3,100	5,150	37	32
Morris Farms	240	380	9.9	68	2,875	10,275	76	44
Martin Farms	220	700	8.3	55	7,775	10,125	37	62
Smith Farms	ND	ND	ND	ND	ND	ND	ND	ND
Four-J Corp.	900	2,500	18	62	1,550	5,600	36	53
Nickel	ND	ND	ND	ND	ND	ND	ND	ND
TLDD Hacienda Ranch	130	590	4.3	76	1,075	5,900	19	30
TLDD South	130	810	7.1	140	970	11,050	19	24
West Farmers	7	18	64	174	1,700	3,700	650	646
Carmel Ranch	800	13,000*	32	840	2,500	40,000	4.1	5.4
Lost Hills Ranch	860	2,600	13	35	2,650	7,000	3.2	10
Rainbow Ranch	5	13	26	260	320	13,250	350	840
Chevron Land Co.	ND	ND	ND	ND	ND	ND	ND	ND

ND = No data.
*Not confirmed by followup analysis.

Source: (Westcot et al., 1988a).

Table 2-7

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS[a]

Evaporation Pond [Basin Number]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food Chain[d]	Significant Biological Effects[e]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Sam Andrews (aka Rainbow Ranch) [26]	Yes	Yes	Brine fly, brine shrimp, damselfly, and water boatman.	---
Barbizon Farms [10]	No	Yes	No	---
Bowman Farms [15]	Yes	Yes	Water boatman.	No deformities of embryos and normal egg hatchability among shorebirds observed during the 1987 nesting season.
Britz South Dos Palos [3]	Yes	Yes	---	---
Britz Deavenport Five Points [5]	Yes	Yes	Midge fly, water boatman, and widgeongrass.	---
Carmel Ranch (aka Willow Creek) [24]	Yes	Yes	Midge fly.	---
Chevron Land Company [27]	---	---	---	---
Carlton Duty [7]	Yes	Yes	---	---
Four - J Corporation [19]	Yes	Yes	---	---
Jackson & Williams Farms (aka Liberty Farms) [13]	Yes	Yes	---	---
Lindemann [2]	---	---	---	---

Table 2-7 (Cont'd)

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS[a]

Evaporation Pond [Basin Number]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food Chain[d]	Significant Biological Effects[d]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Lost Hills Ranch [25]	Yes	Yes	Water boatman.	No deformities of embryos and normal egg hatchability among eared grebes observed during the 1988 nesting season.
Martin Farms [17]	Yes	Yes	Water boatman and widgeongrass.	Reduced egg hatchability among shorebirds observed during the 1987 nesting season.
Meyers Ranch [9]	No	Yes	No	---
Morris Farms [16]	Yes	Yes	Water boatman and widgeongrass.	No deformities of embryos and normal egg hatchability among shorebirds observed during 1987 nesting season.
Nickell [20]	---	Yes	---	---
Sumner Peck [4]	Yes	Yes	Backswimmer, beetle, brine shrimp, damselfly, midge fly, water boatman, and widgeongrass.	Deformities of embryos and reduced egg hatchability among shorebirds (American avocet and black-necked stilt) observed during the 1988 nesting season.
Pryse Farms [14]	Yes	Yes	Water boatman.	Reduced egg hatchability among shorebirds observed during the 1987 nesting season. No deformities of shorebird (American avocet and black-necked stilt) embryos observed during the 1987 nesting season. No deformities of shorebird (American avocet and black-necked stilt) embryos observed during the 1988 nesting season.

Table 2-7 (Cont'd)

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS[a]

Evaporation Pond [Basin Number]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food Chain[d]	Significant Biological Effects[d]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Smith Farms [18]	---	Yes	---	---
Souza [1]	---	---	No	---
Stone Land Company [6]	Yes	Yes	No	---
Tulare Lake Drainage District Hacienda Ranch [21]	Yes	Yes	Midge fly and water boatman.	Reduced egg hatchability among waterfowl observed during 1987 nesting season. No deformities of embryos and normal egg hatchability among shorebirds observed during 1987 nesting season.
Tulare Lake Drainage District North [11]	No	Yes	No	No deformities of embryos and normal egg hatchability among ducks (cinnamon teal, gadwall, mallard, and northern pintail) and shorebirds (American avocets and black-necked stilts) observed during the 1987 nesting season. No deformities of embryos and normal egg hatchability among shorebirds (American avocets and black-necked stilts) observed during the 1988 nesting season. No deformities of duck (cinnamon teal and gadwall) embryos observed during the 1988 nesting season.

Table 2-7 (Cont'd)

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS[a]

Evaporation Pond [Basin Number]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food Chain[d]	Significant Biological Effects[d]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Tulare Lake Drainage District South [22]	Yes	Yes	Midge fly, mosquitofish, water boatman, and widgeongrass.	Deformities of duck (gadwall, mallard, and northern pintail) embryos observed during the 1987 nesting season. No deformities observed in cinnamon teal or shorebird (American avocet and black-necked stilt) embryos during the 1987 nesting season. Reduced egg hatchability among waterfowl and shorebirds observed during 1987 nesting season. Deformities of eared grebe embryos and reproductive failure by colony of eared grebes observed during the 1988 nesting season. No deformities of shorebird (American avocet and black-necked stilt) embryos observed during the 1988 nesting season.
Westfarmers (aka Lost Hills) [23]	Yes	Yes	Algae, backswimmer, brine shrimp, damselfly, water boatman, and widgeongrass.	Reduced egg hatchability among shorebirds observed during the 1987 nesting season. No deformities observed among shorebird embryos during the 1987 nesting season. Deformities of shorebird (American avocet and black-necked stilt) embryos observed during the 1988 nesting season.

Table 2-7 (Cont'd)

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS[a]

Westlake Farms North (#1 & #2) [8]	No	Yes	No	No deformities of shorebird (American avocet and black-necked stilt) embryos observed at Westlake Farms North (#2) during the 1987 nesting season. Reduced egg hatchability among shorebirds observed during the 1987 nesting season. No deformities of shorebird (American avocet and black-necked stilt) embryos observed at Westlake Farms North (#2) during the 1988 nesting season.
Westlake Farms South (#3) [12]	Yes	Yes	Water boatman.	No embryo deformities and normal egg hatchability among shorebirds during the 1987 nesting season.

a "Yes" indicates that based upon available information (see references cited) one or more samples of waters, sediments, and/or food-chain organisms collected from valley evaporation ponds satisfied and/or exceeded the stated threshold concentration (i.e., >5 ppb total selenium for water, >0.5 ppm selenium (dry weight) for sediments, and ≥7 ppm selenium (dry weight) for food-chain organisms). "No" indicates that based upon available information no samples of waters, sediments, and/or food-chain organisms collected from valley evaporation ponds satisfied and/or exceeded the stated threshold concentration. Studies conducted to date may not have been comprehensive and results may not accurately represent all ponds (cells) in a given evaporation pond system. The presence of elevated concentrations of selenium in various environmental media is used here as an indicator of contamination by subsurface agricultural drainage water.

b Data in this column are from water samples analyzed for total recoverable selenium concentrations (Westcot et al., 1988). 5 ppb selenium was selected to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of waterborne selenium.

c Data in this column are from 0"-3" deep, sediment samples (including organic muck layer) (Westcot et al., 1988a).

d Data in this column are from samples of wildlife food-chain organisms collected from valley evaporation ponds (D. A. Barnum and D. S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; S. A. Ford and D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]; T. Heyne, CSUF and M. Kie, CDFG, Fresno, CA [unpublished data]; Schroeder et al., 1988; and White et al., 1987). Brine fly cases have been sampled at many evaporation ponds, however selenium concentrations in those cases are not considered here since it is unknown whether such cases make up a digestible part of the wildlife diet.

Table 2-7 (Cont'd)

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS[a]

Laboratory experiments have demonstrated that selenium in the diet, at concentrations equal to or greater than 8 ppm (dry weight), can harm mallard ducks (i.e., cause deformities [teratogenesis] and deaths of embryos, significant reductions in ducklings produced, and deaths and reduced growth of hatchlings) (Heinz and Gold, 1987; USFWS-PWRC, 1987). Preliminary results of ongoing laboratory experiments have demonstrated that concentrations of selenium in the diet equal to or greater than 7 ppm (dry weight), cause a significant reduction in hatching success (percent of fertile eggs hatched) in mallard ducks (USFWS-PWRC, 1988).

Results of chemical analyses of food chain biota collected from evaporation ponds in the San Joaquin Valley and results of laboratory toxicity studies are now being evaluated to determine if concentrations of other subsurface drainage water contaminants of concern (e.g., arsenic, boron, chromium, and molybdenum) exceed toxic thresholds.

e To date, in addition to studies at Kesterson Reservoir in 1983, 1984, and 1985, and the Grasslands area in 1984, 1986, and 1987, studies of avian reproduction and/or survival of young have been conducted at the following San Joaquin Valley evaporation ponds: Bowman Farms (1987), Lost Hills Ranch (1988), Martin Farms (1987), Morris Farms (1987), Sumner Peck (1988), Pryse Farms (1987 and 1988), Tulare Lake Drainage District Hacienda (1987), Tulare Lake Drainage District North (1987 and 1988), Tulare Lake Drainage District South (1987 and 1988), Westfarmers (1987 and 1988), Westlake Farms North (#2) (1987 and 1988), and Westlake Farms South (#3) (1987). Data from: Ohlendorf (1988); Schroeder et al. (1988); Skorupa (1989); Skorupa and Ohlendorf (1989); and Skorupa and Ohlendorf (1988).

Biological effects discovered at the evaporation ponds include: embryo deformities (overt embryo teratogenesis; gross external deformities/monstrosities); reduced egg hatchability (reduction in the percentage of full-term eggs that hatch, compared with the percentage that would be expected in wild, uncontaminated populations of the same species); and reproductive failure (extremely low or no recruitment [survival of chicks to flight]). Reported are only those biological effects which, based upon statistical analyses, occur at frequencies significantly elevated ($\underline{P} < 0.05$, binomial test) beyond those which would be expected in wild, uncontaminated populations of birds (background conditions).

Ohlendorf et al. (1986a) determined that less than 1% of the nests or eggs of wild populations of birds nesting in uncontaminated environments would have embryos or hatchlings exhibiting major external deformities.

Egg hatchability rates at Tulare Lake Drainage District North (TLDD-N) ponds during the 1987 nesting season were used to establish thresholds against which rates at other pond systems were statistically analyzed. Measurements of egg hatchability at TLDD-N in 1987 revealed that of the nests that were incubated to full-term, 9.5% of shorebird nests and 46.7% of duck nests had 1 or more full-term eggs that failed to hatch.

concentrations in some evaporation ponds. Additionally, uranium occurs at elevated concentrations in most ponds in the valley (Westcot et al., 1988b).

The biological effects documented at the ponds are very similar to those observed at Kesterson Reservoir. It has been clearly demonstrated through controlled laboratory experiments that, by itself and at the same environmental concentrations measured at Kesterson Reservoir, selenium can produce in mallards many of the same biological effects observed at the reservoir (Heinz et al., 1988; Heinz and Gold, 1987; Heinz et al., 1987). As a result of bioconcentration and/or biomagnification, concentrations of selenium and selected other trace elements in food-chain organisms in some evaporation ponds in the valley equal or exceed those measured at Kesterson Reservoir (D. A. Barnum and D. S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; S. A. Ford and D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]; T. Heyne, CSUF, and M. Kie, CDFG, Fresno, CA [unpublished data]; Schroeder et al., 1988; White et al., 1987). To date, 13 of 19 evaporation ponds sampled (approximately 68 percent of the ponds sampled, representing approximately 71 percent of the total acreage of ponds in the valley) contain concentrations of selenium in food-chain organisms at levels equal to or greater than the lowest observed effect concentration (7 ppm dry weight) for mallard ducks (USFWS-PWRC, 1988). Elevated concentrations of selenium have been found in eggs (from species that experienced statistically significant embryo deformity rates in 1987) from one of the two ponds in which such embryo deformities occurred in 1987 (Skorupa and Ohlendorf, 1989).

Biological effects studies conducted to date at evaporation ponds in the valley have focused on impacts upon reproduction and survival of breeding aquatic birds. Wintering use of the ponds by migratory birds exceeds use for

breeding. The effects upon wintering birds of seasonal exposure to elevated concentrations of selenium and other drainage-water contaminants in evaporation ponds in the valley are unknown. Contaminant exposure could potentially impact Pacific Flyway migratory bird populations by directly affecting survival of adult birds by killing them outright or affecting disease resistance (disease is a common cause of mortality among waterfowl wintering in the valley [Gilmer et al., 1982]), and/or indirectly affecting population recruitment by affecting birds' ability to migrate and/or breed (many waterfowl that winter in the San Joaquin Valley migrate enormous distances, to Alaska and northwestern Canada, to breed [USFWS, 1978]). No field studies have yet been conducted to determine the effects on wintering migratory birds of exposure to contaminants at San Joaquin Valley evaporation ponds. USFWS laboratory studies which simulated the overwintering time period while exposing adult mallards to elevated concentrations of selenium in the diet revealed that males began to experience mortality after 16 weeks of exposure to 20 ppm selenomethionine (dry weight) and mortality was 100 percent on an 80-ppm selenomethionine (dry weight) diet, and females that were exposed for 21 weeks to a 15-ppm selenomethionine (dry weight) diet and laid eggs within 2 weeks after cessation of exposure experienced some reproductive impairment (USFWS-PWRC, 1989). Depending upon weather conditions, distance to nesting areas, and other factors, waterfowl may begin egg laying on the northern breeding grounds from days to a month after departing wintering areas in California's Central Valley (pers. comm., April 18, 1989, J. C. Bartonek, Pacific Flyway Representative, USFWS, Portland, OR). Selenium concentrations in key waterfowl food-chain organisms collected from a number of San Joaquin Valley evaporation ponds exceed 20 ppm (dry weight) (D. A. Barnum and D. S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; S. A. Ford and

D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]; T. Heyne, CSUF, and M. Kie, CDFG, Fresno, CA [unpublished data]; Schroeder et al., 1988; White et al., 1987).

It is likely that expansions of existing and/or new evaporation ponds would be constructed in the same general areas in the valley as they exist today, and on either salted-up or other agricultural lands of low productivity, or on currently undeveloped lands. Many of those same undeveloped areas on the valley floor contain remnant San Joaquin saltbush and California prairie vegetation communities, and provide important habitats for endangered species such as the: San Joaquin kit fox; blunt-nosed leopard lizard; giant, Fresno, and Tipton kangaroo rats; and palmate-bracted bird's-beak (a plant).

Because of their attractiveness to aquatic birds, the elevated and increasing concentrations of contaminants in many ponds, and their increasing areal extent relative to wetland acreage in the valley, existing and proposed evaporation ponds represent the most serious threat to the health of aquatic birds of any drainage-related facilities in the valley. Unless management practices change significantly, continued operation of evaporation ponds is likely to continue harming Pacific Flyway birds protected under the Federal Migratory Bird Treaty Act, and potentially affect a population of a candidate species for Federal listing under the Endangered Species Act (western snowy plover). In addition, the expansion of existing and/or development of new ponds on currently undeveloped lands on the valley floor has the potential to adversely affect any or all of the several listed endangered species cited above.

IMPACTS OF DRAINAGE-RELATED PROBLEMS

This section briefly describes the impacts of drainage-related problems as related to the Program's goals concerning: (1) Public health, (2) water quality, (3) agriculture, and (4) fish and wildlife resources.

Public Health

Humans may come in contact with agricultural drainage-water contaminants by direct or indirect routes. Direct exposure may occur by consumption of or exposure to (via skin) contaminated surface or ground waters. Indirect exposure may occur by consumption of contaminated fish or wildlife, plants (either wild or cultivated), or livestock, or exposure to (via skin) contaminated sediments and air (either particulate matter or volatilized metabolites).

With some exceptions, agricultural drainage-water contamination is not expected to be a public health threat through direct contacts; rather, exposures would most likely occur from the indirect means listed above. Drainage waters, per se, usually are collected underground and are diluted with other water sources to which most humans might be exposed. Additionally, many of the mineral substances of concern precipitate readily in local natural water conditions so that dissolved mineral concentrations remain reasonably low, thus reducing the risk of intoxication for at least some of these substances (selenium being an excellent example).

Higher potential levels of human exposure occur, however, when drainage contaminants are bioconcentrated by plants and animals along the transport path or by evaporative processes at the transport terminus (e.g., evaporation ponds). This clearly occurs with at least some mineral contaminants in the western San Joaquin Valley (e.g., selenium).

In April 1987, the SJVDP entered into a cooperative agreement with the Health Officers Association of California to perform a qualitative risk assessment of public exposure to drainage contaminants in the western San Joaquin Valley. In August 1988, the first report was completed (Klasing and Pilch, 1988), which provided available toxicological and local exposure information for the three elements that, because of their relative toxicity and/or unusually high concentration, were considered of most concern in drainage waters: selenium, boron, and molybdenum. The information included in that report as well as additional information obtained subsequently is summarized as follows:

Selenium. Evidence to date indicates that certain types of fish and wildlife in some regions of the western valley have accumulated sufficient concentrations of selenium that health advisories have been issued by the State to restrict consumption. A preliminary survey of local produce throughout the central and southern portions of the western valley and a very small study of domestic ruminants in the Kesterson region have not shown excessive selenium concentrations. Similarly, most domestic water supplies in the valley do not exceed established limits for selenium in drinking water. (The EPA has recently proposed to increase the National Primary Drinking Water Standard for selenium from 10 ppb to 50 ppb [see Federal Register, 40 CFR Parts 141, 142, and 143, May 22, 1989].) Health Surveys of those persons considered at greatest risk for overexposure (primarily Kesterson Reservoir employees and a very small population believed to forage in the area) showed no evidence of selenium intoxication. Cases of environmentally induced (as separate from overconsumption of selenium supplements) selenium intoxication have not been brought to the attention of local or State medical authorities.

Several conclusions can be drawn: (1) Acute selenium intoxication in humans probably does not occur as a result of agricultural drainage-water contamination in the western San Joaquin Valley, and (2) although no evidence has surfaced to date regarding cases of chronic selenium intoxication from drainage-water contamination, knowledge regarding potential negative effects of long-term consumption of selenium in concentrations greater than nutritionally required, and, consequently, methods for detecting such effects are inadequate. Additionally, some potentially exposed populations have not been evaluated. Information regarding public adherence to health advisories also is not available, and (3) the results of field surveys of selenium concentrations in crops and livestock in the area are encouraging but have not been sufficient in scope to assure that isolated problems do not occur (e.g., in cases of subsistence gardening) or provide data adequate for quantitative risk assessment.

Boron. Data regarding negative health outcomes from exposure to high concentrations of environmental forms of boron are not sufficient to assess what, if any, impact on public health results from this element in agricultural drainage waters in the western San Joaquin Valley. Limited information exists regarding boron concentrations in some fish and wildlife; however, boron levels in local crops are not yet available to assist in the determination of likely local intakes of boron, but are scheduled for completion in May 1990.

Molybdenum. Few studies have been performed to assess potential consequences of elevated dietary molybdenum in humans; thus, evaluation of human health effects that may be associated with high levels of molybdenum in the western valley would be difficult. Although State or Federal drinking water standards have not been set for molybdenum, concentrations have been

found to exist in some domestic water supplies in the western valley that would provide more molybdenum than the average American is estimated to receive from the total diet (estimated to range from 120 to 240 ug/day [Tsongas et al., 1980]). Only a small number of samples of edible fish are available to determine the contribution of nondomestic sources to molybdenum in the diet of people in the western San Joaquin Valley; molybdenum concentrations in locally grown produce are not yet available but are expected in May 1990.

Other elements that may pose a potential public health risk currently are under evaluation.

Water-Quality Objectives

The regulation of water quality in streams, rivers, and ground water is the responsibility of the SWRCB and regional water quality control boards.

San Joaquin River Basin. In February 1985, the SWRCB adopted Order No. 85-1, which, in addition to ordering closure, cleanup, and abatement of nuisance at Kesterson Reservoir, established a Technical Committee to provide the following for updating the basin Water Quality Control Plan: (1) Water-quality objectives for the San Joaquin River, (2) effluent limitations for agricultural drainage discharges in the basin, and (3) methods to regulate those discharges. The Technical Committee presented its proposals in its final report, "Regulation of Agricultural Drainage to the San Joaquin River" dated August 1987. The SWRCB adopted the report and its recommendations, which were transmitted to the CVRWQCB for consideration as an amendment to the San Joaquin Basin Water Quality Control Plan. The CVRWQCB has held public hearings and adopted a proposed basin amendment. It will be considered for approval by the SWRCB in fall 1989.

The SWRCB reported that the quality and quantity of the San Joaquin River is strongly influenced by agricultural subsurface drainage discharges. Figure 2-11 shows selected water-quality monitoring locations along the river. There are substantial reaches of the river which have very little flow during much of the year. During the irrigation season, water imported from the Delta is released from Mendota Dam and then is diverted at Sack Dam for irrigation. There is little freshwater flow in the river above the mouth of the Stanislaus River during the irrigation season, except for agricultural drainage. The quality of the river from the mouths of Salt and Mud Sloughs to the mouth of the Merced River is dominated by discharges from those sloughs, which is mainly a combination of surface and subsurface agricultural drainage water. From the mouth of the Merced River to Vernalis, the quality of the river is improved by dilution from east-side tributary flows.

The impact of drainage water carried into the river by sloughs and canals is shown in Figure 2-12. In all cases, discharges from tributary streams and canals from the west side of the river have concentrations of contaminants higher than those of the river.

The SWRCB-recommended objectives for selenium, molybdenum, boron, and total dissolved solids (EC) are shown in Table 2-8. Both interim and long-term objectives were proposed for mean monthly and instantaneous maximum concentrations at several locations on the San Joaquin River and for Salt and Mud Sloughs.

The CVRWQCB has adopted water-quality objectives in the water-quality control plan amendment which differ from those recommended by the Technical Committee and the SWRCB (shown in Table 2-8). The principal changes made by the CVRWQCB for the San Joaquin River from the mouth of the Merced River to Vernalis are:

1. Selenium -

   a. Adopted the monthly mean objective of 5 ppb as proposed by the Technical Committee, but allowed an 8 ppb monthly mean in critical water years. The objective of 5 ppb is to be achieved incrementally by the fall of 1991.

   b. Lowered the allowable instantaneous maximum from 26 ppb to 12 ppb.

2. Salinity - established no salinity objective, whereas the Technical Committee had recommended 1.0 mmhos/cm.

3. Boron -

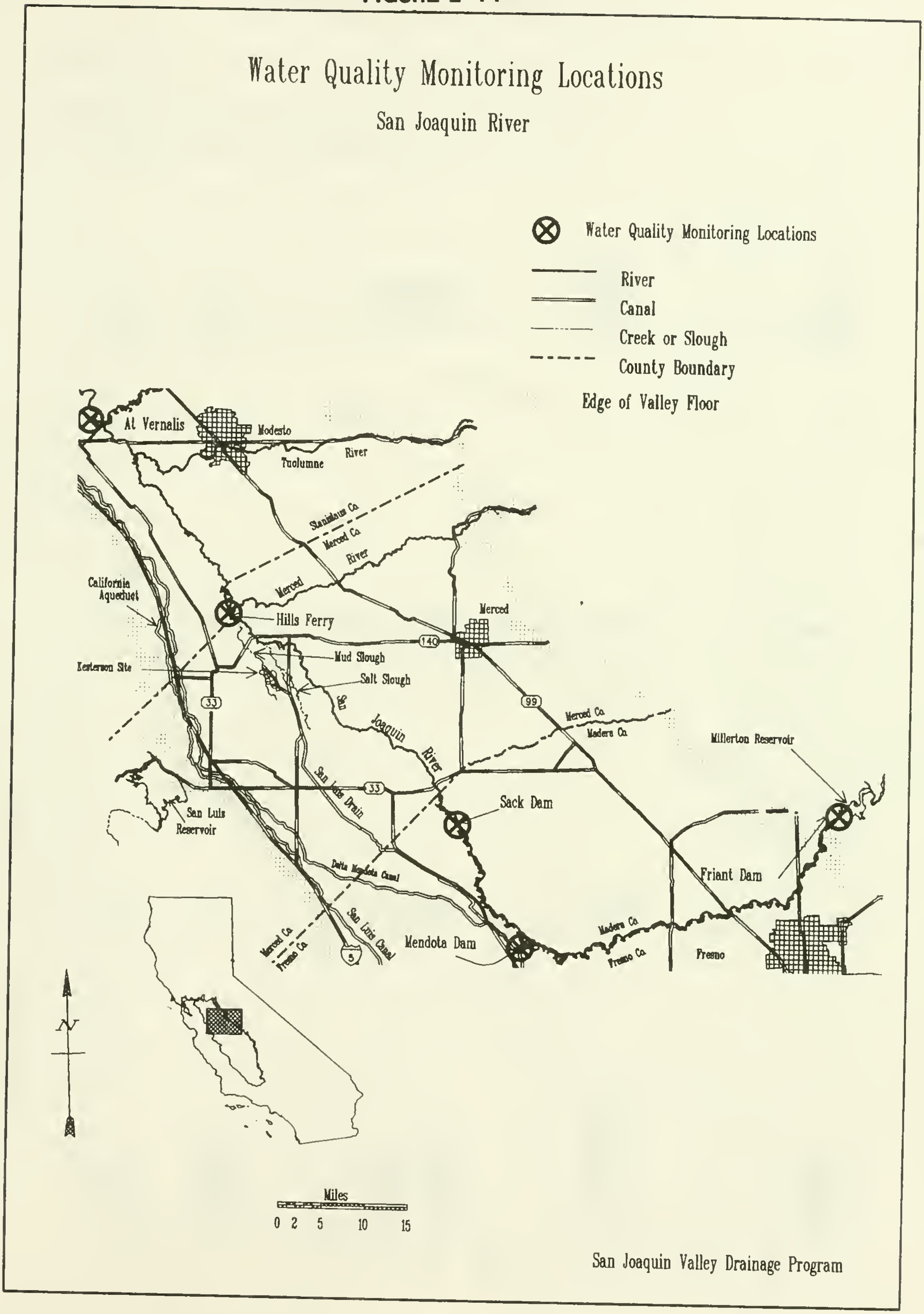
   a. Established monthly mean of 0.8 ppm (March 15 through September 15), 1.0 ppm (September 16 through March 14), and 1.3 ppm (critical water years only), whereas the Technical Committee had recommended a single maximum mean monthly level of 0.7 ppm.

   b. Lowered the instantaneous maximum level from 5.8 ppm to 2.0 ppm (March 15 through September 15) and to 2.6 ppm (September 16 through March 14).

Tulare Lake Basin. The CVRWQCB adopted the Tulare Lake Basin water-quality control plan in 1975. Water-quality objectives for surface waters in the basin focus primarily on protection of beneficial uses in Sierra Nevada foothill rivers and reservoirs. Objectives are set for rivers above and below major reservoirs and for the reservoirs, and include: Kings River (Pine Flat Reservoir), Kaweah River (Lake Kaweah), Tule River (Lake Success), and Kern River (Lake Isabella).

Maximum mean monthly water-quality objectives, measured in ppm, include: Arsenic--0.01, Boron--0.50, Cadmium--0.01, Hexavalent chromium--0.05,

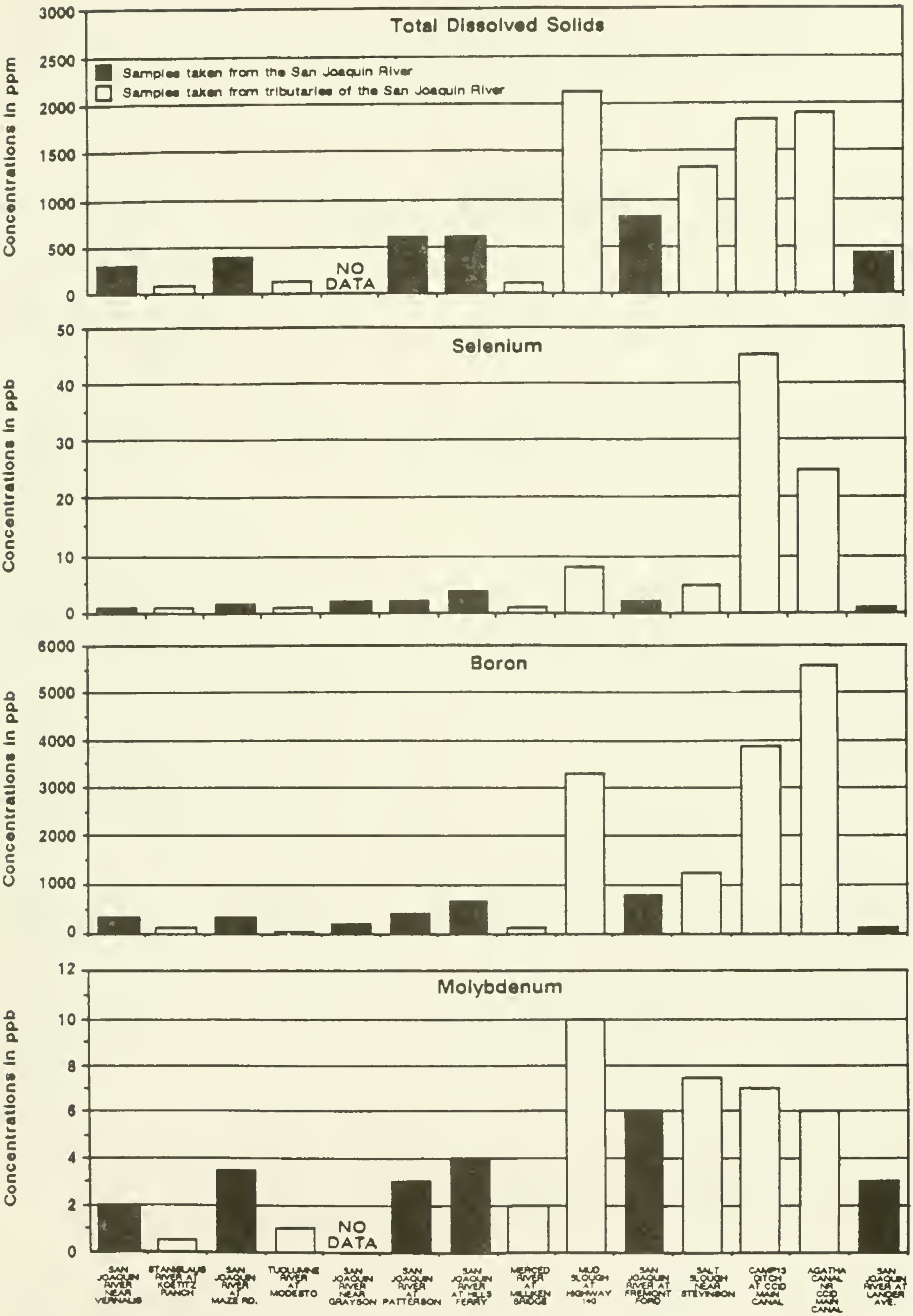
FIGURE 2-11



Water Quality Monitoring Locations
San Joaquin River
Water Quality Monitoring Locations
River
Canal
Creek or Slough
County Boundary
Edge of Valley Floor
At Vernalis
Modesto
Tuolumne
River
Stanislaus Co.
Merced Co.
Merced
River
California Aqueduct
Hills Ferry
Merced
140
Mud Slough
Kesterson Site
Salt Slough
33
San
Joaquin
River
99
Merced Co.
Madera Co.
Millerton Reservoir
San Luis Drain
33
Sack Dam
San Luis Reservoir
Friant Dam
Delta Mendota Canal
San Luis Canal
Merced Co.
Fresno Co.
5
Mendota Dam
Madera Co.
Fresno Co.
Fresno
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 2-12

Water Quality Constituents at Selected San Joaquin River and Tributary Locations



Source: SWRCB Technical Committee Report, August 1987

Note: Samples taken during period May 1984 through July 1986. Number of samples varies from station to station. Bars are median of samples taken.

Table 2-8

RECOMMENDED SURFACE WATER-QUALITY OBJECTIVES FOR THE SAN JOAQUIN RIVER BASIN

Location	Constituent	Maximum Mean Monthly Level	Instantaneous Maximum	Compliance Date
Interim Objectives				
San Joaquin River at Hills Ferry and downstream	Selenium	5 ppb	26 ppb	October 1991
Grassland WD, San Luis NWR, and Los Banos SWA	Selenium	2 ppb (Can be provided via substitute supply)[a]		October 1989
Long-Term Objectives				
San Joaquin River at Hills Ferry and downstream	Selenium	To be determined based on site-specific data		To be determined
	EC	1.0 mmhos/cm		
	Boron	700 ppb	5,800 ppb	
	Molybdenum	10 ppb	440 ppb	
Salt & Mud Sloughs & San Joaquin River Lander Avenue to Hills Ferry	Selenium	10 ppb	26 ppb	To be determined
Salt Slough & San Joaquin River Lander Avenue to Hills Ferry	EC	3.0 mmhos/cm		To be determined
	Boron	2,000 ppb	5,800 ppb	
	Molybdenum	10 ppb	440 ppb	
Grassland WD, San Luis NWR, and Los Banos SWA	Selenium	To be determined based on site-specific data (can be provided via substitute supply)[a]		To be determined

[a] If a substitute supply of 2 ppb or better is provided, the quantity of this supply should be in a volume equal to the lesser of either: (1) The quantity of water historically (mid-1970's) diverted by these waterfowl areas, or (2) the actual flow in the canals available to these areas.

Source: Table VIII-1, Regulation of Agricultural Drainage to the San Joaquin River, SWRCB, 1987.

Selenium--0.01, Silver--0.01, and Zinc--0.01. Maximum mean monthly EC objectives, measured in microsiemens/cm, range from 100 to 450, depending upon the river system and the specific reach of the river.

The only other objective for protecting surface waters (excluding evaporation ponds) states that "surface waters of the Basin shall not be polluted from agricultural wastewater."

Objectives for protection of ground water in the basin plan are in terms of setting maximum average annual increases in EC by hydrographic units:

Hydrographic Unit	Maximum Average Annual Increase (uS/cm)
Westside--North and South	1
Kings River	4
Tulare River and Kaweah River	3
Tule River and Poso Creek	6
Kern River	5

The basin plan acknowledges the need for establishing discharge requirements to ensure protection of beneficial uses from discharge, storage, or conveyance of agricultural and other types of wastewater. Resolution 83-104, an amendment to the basin plan, discusses the need for establishing, on a case-by-case basis, a waste discharge report (WDR). In 1988 the CVRWQCB established a requirement that for evaporation ponds the WDR should include a written agreement between individual pond owner/operators and the DFG establishing guidelines for minimizing adverse impacts on fish and wildlife from the storage of contaminant-laden drainage water.

Recently the CVRWQCB adopted Resolution 89-098 (pending approval by the SWRCB). This proposed amendment to the basin plan, if adopted, would declare that:

all surface and ground waters within the Tulare Lake Basin which currently have no beneficial use designation are hereby designated municipal and domestic supply (MUN), with the exception of:

a. Surface and ground waters where the total dissolved solids (TDS) exceed 3,000 ppm (5,000 uS/cm, electrical conductivity) and it is not reasonably expected by the Regional Board to supply a public water system, or where

b. there is contamination, either by natural processes or by human activity (unrelated to a specific pollution incident), that cannot reasonably be treated for domestic use, and in surface waters where

c. the water is in systems designed or modified for the primary purpose of conveying or holding agricultural drainage waters, provided that the discharge from such systems is monitored to assure compliance with all relevant water-quality objectives as required by the Regional Board.

Apparently there is no current effort on the part of the CVRWQCB to modify the Tulare Lake Basin Plan beyond implementation of Resolution 89-098.

Agriculture

As previously indicated, the amount of irrigated land affected by shallow ground water is continuing to increase in the Westlands, Tulare, and Kern Subareas. The areas affected in the Northern and Grasslands Subareas should not expand as long as they can be drained to the San Joaquin River. By the year 2000, the total number of irrigated acres in the principal study area affected by shallow ground water (5 feet or less from the land surface) could

expand from 847,000 acres now to about 1 million acres, or nearly 40 percent of the irrigated agricultural land in the study area.

Other impacts upon agriculture could include: (1) Reduced crop productivity, (2) lost income due to conversion from salt-sensitive to salt-tolerant crops, (3) increased costs of drainage management, and (4) taking irrigated agricultural land out of production.

A number of water-quality regulatory actions are under way which have the potential of limiting or curtailing drainage-water disposal options, with related potential major economic effects on agriculture. These include: guidelines for evaporation ponds (for construction and operation relative to waste discharge permits); enforcement of certain State and Federal laws, such as the Federal Migratory Bird Treaty Act and the Federal and California Endangered Species Acts; and limits on discharge to the San Joaquin River system.

Fish and Wildlife Resources

Toxicity of Drainage-Water Substances of Concern. Controlled laboratory studies have clearly demonstrated that elevated waterborne and/or dietary concentrations of a number of trace elements carried in drainage water can be toxic to fish and wildlife. To date, selenium has received most attention; however, as noted elsewhere, other substances (e.g., arsenic, boron, chromium, molybdenum, and uranium) also occur in elevated concentrations in drainage waters in the valley (SWRCB, 1987; Westcot, 1988a and b).

Elevated concentrations of selenium are believed to have been responsible for the severe problems with reproduction and survival experienced by aquatic birds at Kesterson Reservoir in the early to mid-1980's (Hoffman et al., 1988; Ohlendorf, 1989; Ohlendorf and Skorupa, in press; Ohlendorf et al., 1988; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b; Williams, 1986). The EPA

ambient, freshwater aquatic life water-quality criterion for selenium was recently reduced from 35 ppb to 5 ppb (USEPA, 1987). The SWRCB and the CVRWQCB recently recommended that waters used for wetlands-wildlife management contain average selenium concentrations of 2 ppb or less (CVRWQCB, 1988a; SWRCB, 1987). These regulatory actions were taken in part because recent toxicity research has clearly demonstrated that higher concentrations pose threats to fish and wildlife.

It has also been discovered that some chemical forms of selenium are considerably more toxic than others. For example, recent laboratory research has demonstrated that waterborne selenite (one of two inorganic forms of selenium carried in elevated concentrations in many subsurface drainage waters) can be more toxic to young chinook salmon than selenate or organic selenium (USFWS-NFCRC, 1986). Conversely, waterborne concentrations of organic selenium are more toxic than inorganic selenium to Daphnia (aquatic invertebrate), bluegill, and striped bass (USFWS-NFCRC, 1988; USFWS-NFCRC, 1987; USFWS-NFCRC, 1986). However, the diet appears to be the most important exposure pathway for selenium uptake by fish and wildlife (USFWS-NFCRC, 1988). Organic selenium compounds are believed to be the most common forms of selenium in biota (including fish and wildlife food-chain organisms), are readily taken up and accumulated, and, in dietary exposure, can be much more toxic than the inorganic forms of selenium (Heinz et al., 1988; Heinz et al., 1987; USFWS-NFCRC, 1988; USFWS-NFCRC, 1987; USFWS-PWRC, 1988).

Recent evidence from a number of selenium toxicity studies reveals that the bioavailability of selenium in water and soils is affected by a number of environmental variables including: pH, salinity, and hardness of water; clay content and texture, organic matter content, and redox potential of soils; and the presence of other chemical constituents, such as sulfate. The toxicity of

selenium is dependent upon, among other factors: its chemical form; ratios among various forms; the fish or wildlife species of concern; the life stage of the organism (although not always true, young animals generally appear more sensitive to selenium toxicity than older animals); and percent of protein in the diet (low dietary protein increases selenium toxicity) (USFWS-NFCRC, 1988; USFWS-NFCRC, 1987; USFWS-PWRC, 1989).

Recent laboratory research has demonstrated that selenium in mallard diets at concentrations of 8 ppm (dry weight) can cause significantly elevated frequencies of deformities (teratogenesis) and deaths of embryos, reductions in ducklings produced, and deaths and reduced growth of hatchlings (Heinz and Gold, 1987; USFWS-PWRC, 1987). Mallard diets containing 7 ppm selenium (dry weight) can cause significant reductions in hatching success (percent of fertile eggs hatched) (USFWS-PWRC, 1988). Some research biologists believe that the safe dietary concentration for waterfowl may be 3 ppm selenium (dry weight) (Wallenstrom, 1986). The biological effects of dietary selenium concentrations between 3 and 7 ppm (dry weight) are unknown.

The DFG recently adopted a selenium standard (affecting operation of evaporation ponds) in an attempt to reduce contaminant-related wildlife effects. The new DFG standard requires initiation of special management actions (e.g., hazing) when mean selenium concentrations in aquatic invertebrates exceed 4 ppm (dry weight). Tissue residues form a variety of aquatic bird food-chain organisms collected from a number of evaporation ponds in the San Joaquin Valley exceed 7 ppm selenium (dry weight). (See Table 2-7.)

Findings from recent laboratory research reveal that boron, which was previously thought to be nontoxic to wildlife, can have adverse effects upon wildlife at concentrations of 900 ppm (dry weight) in the diet (USFWS-PWRC,

1988; USFWS-PWRC, 1987). Samples of aquatic plants (which form part of the diet for some water birds) collected from Kesterson Reservoir and several other evaporation ponds in the valley have been found to contain concentrations of boron which exceed this toxic threshold (S. A. Ford and D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA, [unpublished data]; R. L. Hothem and H. M. Ohlendorf, USFWS-PWRC, Davis, CA, [unpublished data]; Schuler, 1987).

It has been hypothesized that exposure to drainage-water contaminants may also have a broad range of sublethal effects that could significantly impact survival of fish and wildlife populations. Examples of such potential effects upon migratory birds include: the ability to resist disease (especially important on crowded wintering grounds [Gilmer et al., 1982]), the ability to migrate from wintering areas in California to breeding areas in the far north, and the ability to successfully breed and raise chicks to flight stage. Similar effects may also apply to populations of anadromous fish or resident populations of fish and wildlife. The effects of exposure to drainage-water contaminants on these essential biological functions is very poorly understood.

The toxicity of drainage-water constituents is also influenced through chemical interactions with other substances. Understanding of such interactions is extremely limited. It is believed that, in addition to independent action, additive, antagonistic, and synergistic interactions may all occur (USFWS-NFCRC, 1987; USFWS-PWRC, 1988).

Although great strides have been made in our understanding of the toxicity to fish and wildlife of some substances of concern in drainage water, significant data gaps remain. At present, it is very difficult to accurately predict the biological effects that would be expected to occur through the

exposure of fish and wildlife to drainage-contaminated habitats. Recent research has demonstrated that some trace elements carried in drainage water can be much more toxic to fish and wildlife than previously believed. Substantial additional toxicity research is warranted.

Drainage-Water Contamination. Contamination field studies conducted during the past several years have clearly documented elevated concentrations of drainage-water contaminants in water, sediments, food-chain organisms, and fish and wildlife in a number of locations in the San Joaquin Valley in addition to Kesterson Reservoir and the San Luis Drain. In several of these fish and wildlife habitats elevated contaminant concentrations exceed documented toxicity thresholds, and adverse biological effects (that are believed to be contaminant-related) have been documented.

In the San Joaquin Basin, drainage water no longer flows through the San Luis Drain into Kesterson Reservoir. The reservoir has been dewatered, its emergent marsh vegetation cut down and plowed under, and low-lying areas have been filled. In addition, almost all public and private wetlands managers in the Grasslands area have discontinued use of subsurface drainage water for wildlife management.

However, the same raw (untreated) drainage water that used to pass through (and be cleansed by) wetlands in the Grasslands area enroute to the San Joaquin River is now being discharged directly into drainage ditches, canals, Mud (North) and Salt Sloughs, and other tributaries to the San Joaquin River. As a result, the San Joaquin River is currently receiving increased flows of drainage water and increased contaminant loads. In the Tulare Basin, the number and size of evaporation ponds receiving raw drainage water has continued to increase, their areal extent relative to other uncontaminated aquatic and wetland habitats is increasing, and waterborne concentrations of

selenium and some other drainage-water substances of concern are increasing. Concentrations of drainage-water contaminants and adverse biological effects documented at those ponds were previously discussed.

As noted earlier, elevated concentrations of selenium are believed to have been responsible for the biological problems documented at Kesterson Reservoir. Selenium occurs in elevated concentrations in many subsurface drainage waters produced on the west side and southern end of the San Joaquin Valley (SWRCB, 1987; Westcot et al., 1988a), thus its presence in elevated concentrations is used as an indicator of drainage contamination. Although environmental samples have not been collected and chemically analyzed from all areas of the valley, existing data clearly reveal that elevated concentrations of selenium occur in water, sediments, food-chain organisms, and/or fish and wildlife in: Federal and State wildlife areas throughout the valley; ditches, canals, sloughs, and other west-side tributaries to the San Joaquin River; private wetlands in the western Grasslands area; the San Joaquin River; and evaporation ponds in the southern San Joaquin Valley.

Comprehensive field studies of wildlife reproduction and survival have only been conducted at a handful of sites in the valley. Significant rates of adverse biological effects (such as nesting failures, deaths and deformities of embryos, and mortality among adults) have been documented at Kesterson Reservoir and in 7 of 12 evaporation ponds studied. These biological impacts are believed to be related to drainage contamination. Extensive biological effects studies conducted at Volta Wildlife Area from 1983-1985 revealed no deformities and normal reproduction (Presser and Ohlendorf, 1987; Ohlendorf et al., 1986b; Williams, 1986). Studies of tricolored blackbirds at San Luis National Wildlife Refuge in 1987 revealed successful fledging. Descriptions

of drainage-related fish and wildlife problems in each planning subarea are presented in Chapter 4.

During the past few years the USBR has funded through the SJVDP approximately $8.6 million in drainage and drainage-related studies conducted by the USFWS. In addition, other agencies have spent millions of dollars of public funds (primarily in the Grasslands area) in an attempt to minimize or avoid contamination of fish and wildlife by subsurface drainage water and reduce some of the adverse effects of that contamination. A few examples of some of those drainage-related public expenditures follow.

In an attempt to protect public health, by reducing the exposure of duck hunters to selenium-contaminated wildlife from Kesterson Reservoir, the USFWS conducted a hazing program at the reservoir from 1984 through 1988. That program cost about $200,000/year. From February 1985 to the present, the DFG hazed birds away from the Tulare Lake Drainage District Hacienda and South evaporation pond systems. That program cost at least $25,000/year (pers. comm., June 5, 1989, M. Kie, Associate Wildlife Biologist, CDFG, Fresno, CA).

Water control structures and conveyance facilities are being substantially modified in the Grasslands area in a three-phase effort to separate drainage water from freshwater and ensure that freshwater can be delivered to public and private wetlands throughout the area. Construction of phases I and II has been completed at a cost of $1.1 million. The DWR invested $1.1 million in the project, and several local water and drainage districts provided additional water for wetlands management (estimated to be equal to about 10 percent of project costs) in lieu of funding. Construction of phase III is about 80 percent complete and is estimated to cost approximately $1.6 million. Funding of this phase of the project is being contributed by DWR ($985,000), the California Wildlife Conservation Board

($450,000), and local water and drainage districts (about $150,000-$160,000) (pers. comm., June 5, 1989, D. Marciochi, Manager, Grassland Water District, Los Banos, CA).

As a result of drainage-water contamination of Salt Slough, waters from the slough (for which San Luis National Wildlife Refuge has a 19,000 acre-foot/year water right) are no longer usable for refuge wetland-wildlife management purposes. In order to get water to the refuge, an existing water conveyance system was substantially upgraded. The USFWS paid $2.2 million for the construction costs of this project. The costs to deliver clean freshwater to the refuge are now about 70 percent higher than pumping of Salt Slough water (pers. comm., May 31, 1989, J. E. Houck, Principal Assistant Refuge Manager, USFWS, San Luis NWR, Los Banos, CA).

As a result of unnaturally high flows of drainage water entering the San Joaquin River from the west side of the valley (through Mud and Salt Sloughs), upstream migrating adult chinook salmon are being attracted into these sloughs instead of the Merced River. Concentrations of drainage-water contaminants are elevated in these west-side sloughs and there is no spawning habitat there. Consequently, in 1988 the DFG began a major fish rescue program including: the construction and operation of a steep-pass fish ladder and trapping station on San Luis Canal at Los Banos Wildlife Area, and electric barriers on downstream tributaries (to direct the fish toward the trap); and trucking of captured fish to the east side of the valley for spawning and rearing. Construction and operation of these Grasslands facilities (from September to December 1988) cost $50,000-75,000. Future costs are estimated to be about $100,000/year (pers. comm., June 5 and June 19, 1989, W. E. Loudermilk, Associate Fish Biologist, CDFG, Fresno, CA).

CHAPTER 3. OPTIONS

A wide range of potential measures have been identified for solving or helping to solve drainage and drainage-related problems in the San Joaquin Valley. This chapter presents individual options identified by the Drainage Program, including measures that are currently being practiced as well as those that are as yet unproven and still under investigation.

Table 3-1 lists individual options identified so far by the Drainage Program. These options generally fall into seven categories:

- Source control -- Modification of existing on-farm water and land management practices to reduce drainage-water volumes and/or salt and trace-element loads.
- Ground-water management -- Pumping to lower ground-water levels and reduce or obviate the need for subsurface drainage facilities.
- Drainage-water treatment -- Methods for removal of salts, selenium, and other substances of concern from drainage water.
- Drainage-water reuse -- Reuse of drainage water to reduce the total volume requiring treatment or disposal.
- Drainage-water disposal -- Permanent or temporary disposal of drainage water (limited to in-valley measures).
- Fish and wildlife measures -- Actions to protect, restore, provide substitute water supplies for, and improve fish and wildlife resources affected by agricultural drainage.
- Institutional changes -- Modification of laws, regulations, and policies to help solve drainage problems or to facilitate implementation of measures to solve drainage problems.

TABLE 3-1

OPTIONS FOR SOLVING DRAINAGE AND RELATED PROBLEMS

NO.	OPTION	STAGE OF DEVELOPMENT				
		CONCEPT	RESEARCH	DEVELOP-MENT	TESTING AND EVALUA-TION	IN USE OR AVAILABLE*
A	SOURCE CONTROL					
	Water Conservation					
1	Improve Existing Irrigation Practices and Adopt New Irrigation Methods					X
2	Improve Irrigation Scheduling					X
3	Improve Management of Irrigation Systems					X
4	Deliver Irrigation Water on Demand					X
5	Intercept or Reduce Seepage from Major Facilities					X
6	Modify Farm Tillage Practices					X
	Drainage Management					
7	Separate Subsurface Drainage from Surface Drainage					X
8	Recycle Surface Drainage					X
9	Manage Water Table to Increase Contribution to Crop ET				X	
10	Reduce On-Farm Drain Spacing to Minimize Interception of Drainage with High-Contaminant Concentrations					X
	Crop Management					
11	Grow Crops Tolerant of Salts, High Water Table, and/or Drought Conditions		X			
12	Cultivate Crops that Have Minimal Water Requirements		X			
13	Grow Selenium-Accumulating Crops or Selenium-Volatilizing Crops to Reduce Soil Contamination (See D-1)		X			
	Alternate Land Use					
14	Cease Irrigation of Lands with Elevated Trace-Element Concentrations (Land Retirement)					X
15	Convert Irrigated Agricultural Lands to Upland Habitat				X	
16	Convert Irrigated Agricultural Lands to Wetland Habitat					X

* In use now or available for application based on an analysis of costs, effectiveness, and general suitability.

TABLE 3-1 -- continued

OPTIONS FOR SOLVING DRAINAGE AND RELATED PROBLEMS

NO.	OPTION	STAGE OF DEVELOPMENT: CONCEPT	RESEARCH	DEVELOP-MENT	TESTING AND EVALUA-TION	IN USE OR AVAILABLE*
B	GROUND-WATER MANAGEMENT					
1	Pumping from Below the Corcoran Clay					X
2	Pumping from the Sierran Sediments				X	
3	Pumping from the Coast Range Alluvium				X	
4	Pumping Shallow Ground Water	X				
5	Managing Shallow Ground Water (See A-9)				X	
C	DRAINAGE-WATER TREATMENT					
	Biological Processes for Removal or Immobilization of Selenium					
1	Anaerobic-Bacterial			X		
2	Facultative-Bacterial			X		
3	Microalgal-Bacterial			X		
4	Microbial Volatilization of Selenium in Evaporation Ponds		X			
5	Microbial Volatilization of Selenium from Soils and Sediments				X	
	Physical and Chemical Processes for Removal of Selenium					
6	Geochemical Immobilization		X			
7	Iron Filings				X	
8	Ferrous Hydroxide			X		
9	Ion Exchange			X		
10	Reverse Osmosis to Remove Salts and Contaminants				X	
11	Generate Electric Energy and Heat for Desalinization with a Cogeneration Process				X	

* In use now or available for application based on an analysis of costs, effectiveness, and general suitability.

TABLE 3-1 -- continued

OPTIONS FOR SOLVING DRAINAGE AND RELATED PROBLEMS

NO.	OPTION	STAGE OF DEVELOPMENT				
		CONCEPT	RESEARCH	DEVELOP-MENT	TESTING AND EVALUA-TION	IN USE OR AVAILABLE*
D	DRAINAGE-WATER REUSE					
1	Reuse Subsurface Drainage Water for Agriculture				X	
2	Use for Fish and Wildlife (See F-11)				X	
3	Use for Cooling Water for Fossil-Fueled Power Generation Plants		X			
4	Use in Solar Ponds to Concentrate Heat for Production of Electrical Energy			X		
5	Recover and Sell Salts from Evaporation Ponds					X
6	Use in an Aquaculture System		X			
E	DRAINAGE-WATER DISPOSAL					
1	Discharge Drainage Water to the San Joaquin River without Dilution					X
2	Discharge Drainage Water to the San Joaquin River with Dilution					X
3	Clean, Modify, Extend, and Use the San Luis Drain to Transport Drainage Water from Highway 152 to San Joaquin River					X
4	Clean and Use the San Luis Drain South of Mendota to Convey Drainage Water					X
5	Evaporate Drainage Water in Ponds					X
6	Transport and Dispose of Drainage Water into Shallow Ground-Water Aquifer Depressions	X				
7	Inject Drainage Water into Saline Water Underlying the Zone of Freshwater	X				
8	Inject Drainage Water into Deep Geologic Formations			X		
9	Transport Drainage Water to East Side of Valley for Reuse on Irrigated Lands	X				

* In use now or available for application based on an analysis of costs, effectiveness, and general suitability.

TABLE 3-1 -- continued

OPTIONS FOR SOLVING DRAINAGE AND RELATED PROBLEMS

NO.	OPTION	STAGE OF DEVELOPMENT				
		CONCEPT	RESEARCH	DEVELOP-MENT	TESTING AND EVALUA-TION	IN USE OR AVAILABLE*
F	FISH AND WILDLIFE MEASURES					
	Protection of Fish and Wildlife Resources					
1	Planning, Environmental Assessment, and Mitigation					
	o Apply Existing laws					X
	o Develop New Laws	X				
2	Regulation of Take of Fish and Wildlife					
	o Apply Existing laws					X
	o Develop New Laws	X				
3	Regulation of Land and Water Uses					
	o Apply Existing laws					X
	o Develop New Laws	X				
4	Water-Quality Control					
	o Direct Regulation					X
	o Financial Incentives	X	X	X		
	Restoration of Fish and Wildlife Resources					
5	Flooding and Flushing with Freshwater					X
6	Soil and Vegetation Management			X	X	
7	Cultivation and Harvesting of Selenium-Accumulating Plants (See A-13)	X				
8	Microbial Volatilization (See C-4 + C-5)			X	X	
9	Geochemical Immobilization (See C-6)		X			
10	Sequential Implementation of Decontamination and Restoration					X
	Substitute Water Supplies for Fish and Wildlife Resources					
11	Reuse of Subsurface Agricultural Drainage Water	X	X			
12	Reallocation of Freshwater Supplies (See G-16)	X				
13	Altered Sequence of Water Delivery	X				
14	Modification to Existing or Proposed Water Storage Projects and Delivery Systems	X				X
15	Wetlands Water Storage					X

* In use now or available for application based on an analysis of costs, effectiveness, and general suitability.

TABLE 3-1 -- continued

OPTIONS FOR SOLVING DRAINAGE AND RELATED PROBLEMS

NO.	OPTION	STAGE OF DEVELOPMENT				
		CONCEPT	RESEARCH	DEVELOP-MENT	TESTING AND EVALUA-TION	IN USE OR AVAILABLE*
	Improvement of Fish and Wildlife Resources					
16	Agroforestry (See D-1)				X	
17	Management, Development, Reclamation & Acquisition of Fish & Wildlife Habitats and Associated Public-Use Facilities			X		X
18	Uncontaminated Evaporation Ponds - Wetlands	X				X
G	INSTITUTIONAL CHANGES					
1	Increase Price of Water through Water Supply Contracts					X
2	Water Districts Increase Price of Project Water					X
3	Modify or Eliminate Irrigation Subsidies	X				
4	Require Farmers to Pay Only for Water Actually Used		X			
5	Use Tiered Water Pricing at Water District, CVP, or SWP levels			X	X	X
6	Modify Water-Transfer and Water-Marketing Policy		X	X		
7	Rebate Taxes Based on Total Water Management Efficiency	X				
8	Alter Tax Structures and Rates	X				
9	Authorize Use of CVP and SWP Water for Dilution of Agricultural Drainage		X			
10	Impose Drainage-Effluent Fee	X				
11	Limit Drainage Effluent	X				
12	Trade Drainage-Effluent Discharge Permits	X				
13	Form a Regional Drainage District	X				
14	Allocate CVP and SWP Water to Wetlands with Increased Subsidy	X				
15	Authorize CVP & SWP Water for Environmental & Other Uses before Agriculture	X				
16	Reallocate Water from Agriculture to Fish and Wildlife Uses	X				
17	Reauthorize CVP and SWP to include Fish & Wildlife with Equal Consideration when Allocating Water Resources	X				

* In use now or available for application based on an analysis of costs, effectiveness, and general suitability.

The options are of varying complexity and have also undergone different levels of study or development. Table 3-1 identifies the stage of development for each option in the succession: (1) Concept, (2) research, (3) development, (4) testing and evaluation, and (5) in use or available.

Many of the fish and wildlife measures and institutional changes identified are simply ideas or concepts, without the benefit of any detailed study or evaluation. Other options have progressed to research; e.g., all of the crop management options (source control). Most of the drainage-water treatment processes are in either the development or testing and evaluation stage, and include those such as reverse osmosis that represent a proven technology but are not yet implementable or in use because of some particular shortcoming or constraint, including high cost. Finally, some of the options are technologies, practices, or actions that are now in use or are available for application based on an analysis of costs, effectiveness, and general suitability. These include all or most of the water conservation and drainage management options (source control) as well as several of the drainage-water disposal and fish and wildlife measures.

Studies to date indicate that none of the individual options by themselves or any one category of options will constitute an effective drainage management plan for the San Joaquin Valley. Effective plans to remedy the drainage and drainage-related problems will be comprised of combinations of various options--each combination suited to the particular conditions and problems of specific, individual areas.

Certainly not all of the options warrant the investment of time and money needed to advance them through the full stage of development. The options that prove to most promising will be advanced as planning and the decisionmaking process, including public input, continues.

Following are brief descriptions of the individual options, including evaluations of how well an option works, its major advantages and disadvantages, and costs. Because the options are at different stages of development or have undergone different levels of study or investigation, they cannot all be described with the same degree of detail, completeness, and precision.

SOURCE CONTROL (A)

A logical first step in solving valley drainage problems is to reduce the production of drainage water; that is, to control drainage production at the source. Source-control options encompass a broad array of measures to conserve irrigation water and to manage land and water in ways to reduce the magnitude and adverse effects of drainage and drainage-related problems.

Water Conservation

Irrigation water conservation involves measures to reduce water losses to evaporation, transpiration, and deep percolation, and to protect the quality of affected ground-water and surface-water supplies.

Reducing deep percolation and tailwater losses can be approached at the farm level in several different ways. These losses can be minimized by utilizing the most appropriate irrigation system, by proper management of the system, and by optimum irrigation scheduling. Other measures to improve water conservation include delivery of irrigation supplies on demand, seepage control, and changes in farm tillage practices.

Improve existing irrigation practices and adopt new irrigation methods (A-1). This option includes methods to improve the efficiency and uniformity of irrigation water application, thus reducing deep percolation. Examples include shortening existing furrow lengths, recycling tailwater, and

using water-conserving irrigation technologies such as drip and sprinkler systems or improved furrow methods (CH2M Hill, 1989).

"Deep percolation" refers to that portion of the applied irrigation water which percolates below the crop root zone. In theory, a relatively small amount of deep percolation (0.1 to 0.3 acre-ft/acre) is required to remove salts from the root zone. In practice, deep percolation tends to be considerably greater. For example, in a survey of lands in Westlands Water District in 1987, Burt and Katen (1988) calculated the range of deep percolation as 0.3 to 1.4 acre-ft/acre/yr, with an average of 0.8 acre-ft/acre/yr. According to these investigators, modification of existing irrigation methods such as shortening furrow lengths, installing surface-water recovery and return systems (recycling, reuse) for regular irrigations, and use of sprinklers for preirrigation could reduce deep percolation by 50 to 75 percent in certain fields. This is particularly significant because Westlands actively supports water conservation and, overall, water-use efficiency is higher there than in many other districts in the study area.

Irrigation methods used on the west side of the valley are adapted to soil conditions, normal crop rotation, water availability, and economic conditions as well as to labor and management experience and constraints. Modification of existing methods or adoption of new ones must consider these conditions and constraints.

New methods of irrigation not currently in use in the drainage problem area (e.g., buried drip systems) must be widely demonstrated under a range of conditions before they will be adopted by growers. The University of California and private agribusiness firms are currently conducting various irrigation method demonstrations on the west side of the valley.

The primary advantage of this option is that improved irrigation methods are currently available and, with improved management of irrigation systems (see option A-3), can be implemented fairly quickly by the individual grower. The primary disadvantage is that the initial cost of some irrigation systems may be prohibitive for some growers. Also, it should be noted that at some point in the process of improving water-use efficiencies, the cost of achieving the additional increment of water savings becomes economically infeasible.

Improve irrigation scheduling (A-2). Better information on soil moisture depletion would allow the irrigator to better determine when to irrigate and how much water to apply. This would provide for a reduction of excessive water application and related deep percolation with resultant subsurface drainage. It would also help minimize underirrigation, resulting in increased crop yield. Information essential to improved irrigation scheduling is available from several sources, including California's Irrigation Management Information System program, which provides current weather information necessary to calculate existing levels and rates of soil moisture depletion. Soil moisture sensors can also be used to measure moisture depletion.

The U.S. Soil Conservation Service works with local water agencies and individual growers in evaluating irrigation scheduling procedures and management practices for individual fields and recommends modifications to current irrigation practices. Also, private firms hired by water districts and individual growers assist in irrigation scheduling by collecting field data on soil moisture depletion and providing optimal schedules for irrigations.

The degree of soil texture variability, variation of climatic conditions, and availability of water will limit opportunities for optimal irrigation

scheduling. However, this option is generally beneficial and should be an element of any action plan.

Improve management of irrigation systems (A-3). Improvements in irrigation system management may contribute as much to water conservation and source control as will improvements in actual irrigation methods. Evaluation of several irrigation systems within the Westlands and Grasslands Subareas suggests that irrigation system management is a significant factor in determining overall irrigation application efficiency and deep percolation losses to ground water (Burt and Katen, 1988). For example, a well-managed furrow system can be more efficient than a poorly managed sprinkler system.

In identifying measures to reduce deep percolation, irrigators must reassess the management of their existing systems and consider adoption of improved management techniques. Demonstrations of and instruction in properly managed systems will help growers improve irrigation management skills.

Deliver irrigation water on demand (A-4). Deep percolation can be reduced by delivering sufficient water for irrigation at the optimal time for replacement of depleted soil moisture. Because the present capacity of water-conveyance facilities restricts the quantity and timing of water deliveries to and within some districts on the west side of the valley, growers often must request specific deliveries as much as 3 days in advance of a scheduled irrigation. This lag time between request and delivery increases the risk of stressing crops when changes in weather conditions result in greater-than-anticipated soil moisture losses. To reduce this risk, some growers often irrigate more frequently than necessary and apply significantly more water than crops require (Merriam, 1987).

Federal, State, and local water facilities are generally designed and operated to provide water when it is required. However, in some locations

water delivery flexibility could be increased by the provision of additional conveyance capacity, increased conjunctive use of ground water and surface water, and improvements in coordinated systems operation.

One of the major advantages of this option is that it can effect major changes in the capabilities of supply systems and drainage management systems. The disadvantages of increasing the capacity of existing delivery systems are the capital costs required and the time required to plan, finance, and build structural features.

Intercept or reduce seepage from major facilities (A-5). Seepage from canals operated by individual growers and irrigation districts contributes to deep percolation. Most of the canals in the drainage problem area are earth-lined. Lining canals with concrete or synthetic membranes or intercepting seepage from canal sides could reduce seepage losses. A reduction in conveyance losses would also reduce the total amount of water entering the semiconfined aquifer and/or contribution to subsurface drainage. Detailed studies of individual canal systems are needed to determine benefits and costs of intercepting seepage losses or lining facilities.

Seepage from all canals, ditches, and natural channels on the west side of the valley is estimated to be approximately 600,000 acre-ft/yr, or about 10 percent of the total water delivered to the area. This estimate is based on data obtained from the DWR's Hydrologic-Economic Model, CH2M Hill (1988), and Boyle Engineering Corp. (1988b). Total seepage volume that can be reduced or recaptured has not been determined.

Modify farm tillage practices (A-6). Adoption of specific tillage practices will help improve the uniformity of irrigation water application and reduce deep percolation and the resultant volume of subsurface drainage water. An example is deep tillage to break up fine-textured soils and thus increase

the infiltration rate. In some circumstances it is appropriate to use specialized equipment to reduce the soil infiltration rate, to help ensure better uniformity of water percolation (Boyle Engineering Corp., 1986).

Drainage Management

Drainage management involves reducing drainage-water volume and improving drainage-water quality by separating surface and subsurface drainage, recycling surface drainage, managing the shallow water table, and redesigning on-farm drains.

Separate subsurface drainage from surface drainage (A-7). Separation of surface and subsurface drainage on individual farms is often an essential step in increasing opportunities for drainage-water reuse, treatment, and disposal. Currently, local water and drainage districts often provide joint, but not separate, drainage collection and reuse systems.

With separate drainage management systems, surface drainage may be recycled on-farm to improve irrigation efficiency and uniformity of water application. Subsurface drainage may also be reused on salt-tolerant crops, thereby reducing the volume of drainage water requiring disposal. On west-side farms, separation of surface drainage water also keeps any pesticides (seldom found in subsurface waters on the west side) from becoming commingled with subsurface water, which otherwise potentially could compound management problems.

The overall feasibility of this option in some subareas (e.g., Grasslands) will depend on the water-quality objectives of receiving waters, such as the San Joaquin River--particularly whether the objectives are based on the concentrations of salts and contaminants in receiving waters or on the total load of those substances.

Recycle surface drainage (A-8). This option is principally adaptable to surface irrigation systems in which tailwater is collected and delivered to a small regulatory reservoir, or sump, for reuse on the same field or to a field downslope.

Some water districts, such as Westlands, require growers to recycle surface drainage. In places where irrigation water is relatively inexpensive and surface drainage dilutes subsurface drainage, thus facilitating the meeting of water-quality objectives for the San Joaquin River, there are few incentives for recycling surface drainage.

Recycling of surface drainage can improve overall water-use efficiency and thereby reduce deep percolation and drainage-water volume (CH2M Hill, 1989). The degree of efficiency improvement depends on the surface irrigation method being used. In addition, fertilizers and pesticides contained in surface drainage, when reapplied with recycled water, can in some cases reduce overall farm management costs and reduce nonpoint source pollution.

Manage water table to increase contribution to crop ET (A-9). Control valves inserted in underground drains can be used to hold the shallow ground-water table at a high level and thus increase shallow ground-water contributions to crop consumptive use and irrigation water use. In theory, this technique, when coupled with carefully controlled irrigation scheduling, will maintain salt balance within the root zone of individual crops and also permit controlled releases of drainage water, as necessary, to correspond to drainage-water treatment and/or disposal capacities. The feasibility of this process is currently being determined through field research that includes salt-balance monitoring (J. M. Lord, 1988).

The potential benefits of this option include reduced water requirements, reduced drainage-water volume and salt load, and improved use of fertilizers.

Successful implementation would require more-sophisticated drainage management than is currently practiced on-farm, together with frequent monitoring to control root-zone salinization.

Reduce on-farm drain spacing to minimize interception of drainage with high-contaminant concentrations (A-10). The optimal depth and spacing of on-farm drains vary with the hydraulic characteristics of the shallow ground-water aquifer. On the west side of the valley, the spacing of drains normally varies from 300 to 600 feet. More widely spaced drains tend to intercept water at greater depths than do more closely spaced drains. Throughout most of the study area ground-water degradation increases with depth, with the highest contaminant concentrations below 20 feet. The amount of highly degraded ground water intercepted by the on-farm drains can therefore be reduced with closer spacing and, thereby, reduce the cost of drainage-water disposal. However, drain spacing designed to limit the interception of ground water below 20 feet would significantly increase the cost of installing on-farm drainage systems.

Crop Management

Crop selection and management can reduce the amount of irrigation water applied and, thus, drainage-water volume. For example, the use of more salt- or drought-tolerant crops having lower water requirements can reduce the overall drainage volume.

Grow crops tolerant of salts, high water table, and/or drought conditions (A-11). Certain crops, such as barley and cotton, can tolerate a variety of environmental stresses, including water shortages, high water tables, and high soil salinities. Such crops could be grown on some lands in the drainage problem area to provide (1) increased flexibility in managing drainage by reducing drainage-water volume when conditions are not favorable for disposal,

and (2) an opportunity for growers to continue farming until an economically feasible treatment or disposal system becomes available.

Management practices, including crop rotation, irrigation management, and soil preparation and planting methods, are more critical for crop success under the described stress conditions than under less stressful conditions (Boyle Engineering Corp., 1986). Research is being conducted by the University of California and U.S. Salinity Laboratory in Riverside to evaluate alternative management practices necessary for effective crop production under various stress levels.

Cultivate crops that have minimal water requirements (A-12). In areas underlain by shallow ground water having high concentrations of salts or trace elements, or in areas where soils contain high levels of soluble salts or trace elements, lands may be retired from irrigated agriculture to reduce the production of contaminated drainage water. (See A-14.) Some of these areas could be dry farmed. Additional research is needed to develop crop hybrids that have lower water requirements. But even with such hybrids, dry-land farming would probably be restricted to areas with highest rainfall and/or shallow ground-water levels, to provide the minimum water requirement. Boron and salt concentrations are high in many of the areas with high water tables. Water availability and quality will greatly limit the potential for dry-land farming on the west side of the valley.

Grow selenium-accumulating or selenium-volatilizing crops to reduce soil contamination (A-13). Some plants and crops will take up selenium from soil and water and convert the selenium to organic form and/or volatilize selenium from leaf surfaces. According to Klasing and Pilch (1988), the known aggressive accumulators of selenium (e.g., *Astragalus* [locoweed]) are not commercially grown plants. The only known commercial plants that accumulate

selenium in significant amounts are some species of mustard. Selenium uptake by eucalyptus and atriplex (saltbush) is being measured in research on reuse of subsurface drainage water (CDFA, 1988). (See D-1.) Assuming selenium accumulation proves to be significant, there remains the problem of potential hazards to wildlife and safe disposal or use of the vegetative material. Additional research on selenium-accumulating plants, including greenhouse experiments, is being conducted by the U.S. Department of Agriculture's Agricultural Research Service Water Management Laboratory in Fresno (Banuelos and Schrale, 1989.)

Alternate Land Use

A reduction in irrigated agriculture in areas affected by shallow ground water can be the most effective method of reducing existing and projected drainage-water volumes and salt and contaminant loads. The change in land use can also provide opportunities to increase wildlife habitats in the valley.

Cease irrigation of lands with elevated trace-element concentrations (land retirement) (A-14). Measures that might be used to retire "hot spots" of selenium include:

- o Direct purchase of lands.
- o Irrigation disincentives, including imposition of drainage service fees.
- o Creation of incentives for reducing water application, such as water-marketing profits.
- o Land rental to secure water supply allocations and alternative uses (such as agroforestry or habitat areas).
- o Reclassification of certain CVP project lands as nonirrigable, with related reduction of water allocations.

If the criterion for selecting lands for retirement was any land overlying shallow ground water containing at least 50 ppb selenium in solution, the total land area affected would be 312,000 acres (all subareas combined). If the criterion was lands overlying ground water of greater than 5 ppb selenium, then the candidate land would comprise approximately 566,000 acres.

Retiring land from irrigation would not necessarily reduce total water consumption in the valley, but it could result in some water being directed to different uses and to other areas. At present, about 5 to 10 percent of valley farmland is idled each year as part of normal farming operations, and water saved at one location is often used in other areas. Water marketing could produce revenues for landowners to finance on-farm source-control facilities (e.g., sprinkler systems) to help alleviate drainage problems. This possibility is discussed in more detail under option G-6.

The retirement of land from irrigation would likely be done as part of a drainage management strategy to reduce drainage-water volumes while possibly freeing up water supplies for other uses. It likely would need to be implemented on a water-district basis, and could include incentives for voluntary participation by landowners.

This option would reduce agricultural production, local tax revenues, farm labor, and local income (depending upon the change in land use); it also may induce salinization of the land from irrigation of adjacent lands.

<u>Convert irrigated agricultural lands to upland habitat (A-15)</u>. Lands retired from irrigated agriculture could be managed to provide upland wildlife habitat. Native grasses typical of these lands could be reintroduced; other plants, selected for specific wildlife species, could be cultivated; or natural revegetation could be allowed to take place. Wildlife populations,

possibly including endangered species, could increase as a result of the additional suitable habitat.

A potential disadvantage of this option is the possibility of selenium accumulation in vegetation, and seeds in particular, that could prove hazardous to wildlife. In areas of shallow ground water, salts may also accumulate in the soils, eventually rendering the soils unproductive. Demonstration of this option within the drainage problem area is necessary to enable assessment of its effects on the environment.

Convert irrigated agricultural lands to wetland habitat (A-16). Wetland habitat could be established on retired agricultural lands, principally near the valley trough. Lands with heavily textured soil relatively free of selenium could provide good-quality wetland habitat for wildlife. A firm, contaminant-free freshwater supply of 3 to 4 acre-ft/yr would be required for each acre of seasonal marsh and up to 10 acre-ft/yr for permanent marsh habitats.

Conversion to wetland habitat has taken place in the Grasslands area. However, there has often been an inadequate water supply available to realize the full potential of these lands as wetland habitats.

GROUND-WATER MANAGEMENT (B)

The general relationship between ground-water conditions and subsurface drainage problems is discussed in Chapters 1 and 2. The presence of a shallow, saline ground-water table (which may also contain high concentrations of trace elements) increases the risk of crop yield reductions due to waterlogging and salt buildup in the crop root zone. Growers often install on-farm drains to control water-table levels and avoid adverse effects on crop production.

The source-control (A) options presented above comprise those surface-water and ground-water management options that may be implemented at the scale of an individual field or farm. In contrast, the ground-water options presented here might be more effective at the water district, drainage district, or regional scale.

The options available within each of the planning subareas relate to the natural geohydrological features discussed in Chapters 1 and 2, and consist of: (1) Pumping from the confined aquifer that lies below the Corcoran clay, (2) pumping from the semiconfined aquifer (Sierran sediments), (3) pumping from the semiconfined aquifer (Coast Range alluvium), (4) pumping from the shallow aquifer, and (5) managing shallow ground water.

Pumping from below the Corcoran Clay (B-1). Many wells have been drilled 450-1,000 feet below the land surface within the confined aquifer that lies below the Corcoran Clay. Reduced pumping from the confined aquifer has occurred during the past 20 or 30 years, in response to increased reliance on surface-water supplies, and has reduced the rate of downward movement of ground water through the Corcoran Clay to between 0.2 and 0.6 ft/yr, depending on the location (Gilliom et al., 1988). At present, the volume of water moving downward through the Corcoran Clay helps to reduce the rate of rise of the shallow ground-water table and diminish the volume of drainage water requiring disposal. With continued recharge of the confined aquifer, however, this downward flow will decrease as the piezometric (pressure) head within the confined aquifer rises. This condition will tend to exacerbate the drainage problem.

Increased pumping within the confined aquifer beneath the Corcoran Clay could reverse this trend and contribute, indirectly, to the lowering of shallow ground-water levels. Samples of ground-water quality in the confined

aquifer show concentrations of salt ranging from 500 to 2,800 ppm (Deverel, 1989) and generally no more than trace concentrations of selenium.

There are at least two potential disadvantages to the use of ground water from the confined aquifer: (1) The quality of ground water within the confined aquifer may gradually deteriorate with increased pumping (chloride concentrations would likely increase), and (2) land subsidence, which was a problem on the west side of the valley when ground water was the principal irrigation supply, could recur. Sound planning and management of ground-water pumping can reduce these hazards to a reasonable magnitude.

Pumping from the Sierran sediments (B-2). The characteristics of the Sierran sediments are described in Chapter 2. Field studies have demonstrated good hydraulic connection between these coarse-grained deposits and the overlying, more fine-grained alluvial deposits in the drainage-affected area. Short-term pump tests during the winter of 1988-89 (Schmidt, 1988, 1989) indicated that the shallow water table could be lowered measurably over a radius of several hundred feet from the pumping wells by pumping either at shallow depths, 30 to 60 feet, or at moderate depths, 112 to 244 feet. The long-term sustainability of these pumping regimes has not been determined; however, it is believed that pumping would need to be fairly constant during the growing season in order to maintain a lowered water table.

For the past several decades, the quality of the ground water in the Sierran sediments has been considered suitable for most agricultural uses. In 1989, however, Schmidt reported ground-water salinities of 4,500-4,800 ppm in a test of water in the Sierran sediments. This finding suggests that there may be a trend of increasing salinity in the Sierran sediments, a finding which has been documented by A. Swanson (1987). However, there is no evidence of soluble selenium in detectable concentrations in the Sierran sediments.

Chemically, the Sierran sediments is a reducing environment, which means that selenium does not remain in solution in these sediments. There is a possibility, however, that in time the boundary of this reducing zone (see Figure 1-2) might shift eastward toward pumping depressions which occur on the east side of the valley.

Controlled pumping of water from the Sierran sediments at depths of 60-100 feet, in areas located at the margins of the alluvial fan areas, could lower ground-water tables. Pumping could provide, at least in the short term, a supply of supplemental water low in selenium, although the salinity might require blending if the water is to be used early in the irrigation season or for supplementing fish and wildlife supplies. Investigations are under way by the USGS and the SJVDP to determine some of the long-term impacts of sustained pumping in various drainage problem source areas. Ground-water pumping strategies to manage water tables may require continuous extraction of water if water tables are to be affected regionally.

<u>Pumping from the Coast Range alluvium (B-3)</u>. Pumping of ground water from the Coast Range alluvial deposits could also be effective in lowering shallow ground-water levels. In preliminary investigations, using a numerical ground-water model of the semiconfined aquifer in a subregion of the western valley, the USGS (Gilliom et al., 1988) has shown that pumping from within the Coast Range alluvium (200- to 300-foot depth) could achieve the same effect as on-farm drains in regional management of shallow ground-water levels.

Water quality is a major concern in the semiconfined aquifer in the Coast Range alluvium. Ground water below an average depth of 150 feet may prove to be moderately saline (TDS 1,000-2,500 ppm); fortunately, however, it currently is expected to contain low selenium concentrations (less than 5 ppb). During

pumping, selenium-contaminated ground waters will tend to move downward toward the point(s) of extraction.

It is necessary to be able to predict the rate of movement and depth distribution of the zone of poorer quality water in order to properly evaluate this option. Long-term feasibility of this option will also require specific information on aquifer characteristics, properly engineered well construction, and carefully managed pumping practices.

Pumping shallow ground water (B-4). For Northern Subarea lands located near the San Joaquin River, pumping from the shallow ground water may be a way to reduce the volume of saline ground water seeping into the river during low-flow periods.

Under this option, saline ground water would be pumped into the San Joaquin River when the river stage is relatively high and transport and dilution capacities are large. Pumping would increase the available storage space within the shallow ground-water aquifer, which could then be filled with deep percolation during the irrigation season. The option is workable only in those regions where selenium and other toxicants occur in low concentrations within the ground water and where water-quality regulations allow such discharges to the river.

Managing shallow ground water (B-5). See option A-9.

DRAINAGE-WATER TREATMENT (C)

Various drainage-water treatment process have been investigated at several levels of development. The goal of these investigations has been to identify affordable methods to remove trace elements of concern (mainly selenium) from drainage water.

The various treatment processes have not been investigated equally or developed to the same level of technology. A few processes, such as anaerobic-bacterial treatment, high-rate algal ponds, and ferrous hydroxide, have advanced beyond laboratory bench-scale research; however, investigations on each of these is incomplete and more work with larger scale "pilot prototype" plants is needed to establish technical performance and reliable cost estimates. Moreover, there has been no substantial operational experience with any treatment process.

Treatment work continues, but more reliable information on the effectiveness and cost of the various treatment processes investigated is not presently available. Development of such information requires further pilot-scale research and is essential to make sound treatment management decisions. It is certain that a number of processes will remove selenium, but it is not yet certain how effectively each of the processes could be enhanced and at what cost they would function under field conditions.

The most promising treatment processes are briefly described below. For preliminary planning purposes, cost estimates (with different levels of precision and reliability) have been developed from research data.

<u>Biological Processes for Removal or Immobilization of Selenium</u>

<u>Anaerobic-bacterial (C-1)</u>. EPOC Agricultural Corporation (EPOC AG, 1987) of Fresno has examined an anaerobic-bacterial process by operating a test facility and small-scale plant (24,000 gallons per day [gal/d]) located in Westlands Water District. EPOC AG reported that biological reactors can reduce selenium concentrations in drainage water from 300-550 ppb to 16-50 ppb. With the addition of microfiltration, the concentrations can be reduced further to 10-40 ppb. Following an ion-exchange process, selenium concentrations can be further reduced to less than 10 ppb, while boron

concentrations can be reduced from 10 ppm to less than 1 ppm. Substantial amounts of heavy metals, including molybdenum and chromium, would also be removed through ion exchange as an add-on at the end of the process.

EPOC AG reported that it has over 18,000 hours of operating experience with the anaerobic-bacterial process. Their conclusions are:

- o Biological treatment is a practical and now proven method of removing selenium from drainage water.
- o To gain optimum design performance, biological growths in the reactors should be dispersed rather than grown on fixed films.
- o To obtain engineering design and operational data on the biological reactors and microfiltration system, the technology needs testing in a prototype plant sized up to 1 million gallons per day (Mgal/d). (Note: The ITAC Treatment and Disposal Subcommittee did not concur that the process is ready for this level of testing. The subcommittee recommended testing in a 50,000-gal/d prototype plant.)

EPOC AG estimated that a 1-Mgal/d pilot prototype would cost about \$76/acre-ft for construction and about \$148/acre-ft for operation, totaling about \$224/acre-ft. EPOC AG concludes that full-scale treatment and disposal of agricultural drainage water (10-Mgal/d size) can be accomplished for about \$145 to \$163/acre-ft.

Adjusting EPOC AG's cost data to be consistent with criteria used in SJVDP-sponsored investigations, a full-scale plant would cost from \$150 to \$300/acre-ft to treat water (not including costs to transport drainage water to treatment facilities, land acquisition, a regulating forebay, and waste-stream disposal cost or closure at the end of plant life).

Depending on the chemical composition of the water treated, the cost of waste-stream disposal is expected to vary. However, total costs for the

anaerobic-bacterial and other treatment processes will be substantially higher than the types of costs cited above because the concentrated waste stream will constitute hazardous waste. Disposal of hazardous wastes at the Kettleman Hills Class I Waste Management Unit currently costs about $110/ton for solid wastes and $0.85/gallon for liquid wastes (pers. comm., Anthony Toto, CVRWQCB, Fresno, CA). Disposal costs could be reduced by the removal of water, but handling and drying costs offset these gains; there is an economically optimum level of water removal.

Facultative-bacterial (C-2). Altringer et al. (1987), at the U.S. Bureau of Mines Research Center in Salt Lake City, has been studying selenium-reducing facultative bacteria in laboratory fixed-film static-bed columns and in continuous-flow, rotating biological reactors in which bacteria are fed an organic energy source. The bacteria used in these experiments were *Pseudomonas*, *Salmonella*, and *Citrobacter*. Selenium was reduced from selenate to selenite and then precipitated from solution in elemental form. Selenium removal ranged from about 87 to 96 percent. Research is continuing to improve reactor design, to implement optimal growth conditions, and to develop an understanding of the mechanisms involved in the process.

Microalgal-bacterial (C-3). This process, which is being studied by researchers at UC Berkeley (Oswald, 1985), does not rely on either direct uptake of selenium by algae or precipitation of selenium in high-rate algal ponds. Algae are produced from nutrient-rich drainage water in high-rate ponds and incorporate nitrates in algal cells and provide biomass for methane fermentation.

Sludge from the methane fermentation process has been observed to be effective in reducing selenium. The sludge is introduced into a reduction chamber, where drainage water from the high-rate pond is in contact with the

digested algal biomass. The selenium is then reduced to an insoluble form and is removable. To minimize reactor size, the soluble selenate must be converted as rapidly as possible to an insoluble form. There must also be an adequate, dependable supply of low-cost reducing material; i.e., sludge from the algal digesters. Sufficient electrical energy to operate the system (with some possible surplus) can be produced from methane generated in the digester. Carbon dioxide from the digester is recycled to maintain a pH below 8.3 in the high-rate pond and to provide carbon for microalgal growth.

In laboratory experiments, algae grown on drainage water in ponds at Murrieta Farms (in Westlands Water District) have been reported to ferment and yield methane in the digesters (Oswald et al., 1988). The methane yield was 0.26 liter per gram of volatile solids introduced into the digester. The methane fraction of the total gas was 71-77 percent, indicating a vigorous methanogenic bacterial culture. This methane production was achieved when algal sludge was concentrated before digestion to diminish sulfate and nitrate levels in the digester feed.

With the increased methane yields, reductant strength also increased. Selenium removals in the continuous feed process have reached 80 percent. Further improvement in removal rate is expected with the installation of two larger silo-type digesters. Analysis shows that some selenate may be reduced without complete denitrification, but most of the nitrate must be removed to reduce selenate concentration down to a targeted level of 5 ppb.

The researchers' current estimate of costs for design, construction, and operation and maintenance of an algal-bacterial selenium-removal system is about $272 to treat 1 acre-ft of drainage water for a 1-Mgal/d plant and about $103/acre-ft for a 10-Mgal/d plant.

Microbial volatilization of selenium in evaporation ponds (C-4). Researchers at UC Riverside have studied a process to attempt to maintain selenium levels in evaporation ponds below 1 ppm. The study involves a means to increase the rate of natural microbial volatilization from drainage water.

Alternaria alternata was isolated as an active selenium methylating organism occurring naturally in evaporation pond waters (Frankenberger and Thompson-Eagle, 1988). The optimum pH and temperature for methylation were 6.5 and 30 ^{o}C, respectively.

Pond-water samples ranging in selenium concentration from 14 to 2,000 ppb were laboratory tested to simulate selenium biomethylation. With no amendments to a pond-water sample, the natural formation of dimethylselenide, a nontoxic form, was less than 1 percent of the total selenium inventory after 40 days of incubation. The addition of carbon sources, such as glucose, maltose, sucrose, and galacturonic acid, at 2 grams per liter carbon did not enhance selenium methylation to any great extent. However, the addition of three proteins--egg albumen, casein, and gluten--dramatically increased methylation over the controls at all concentrations tested. After 43 days of incubation, albumen caused 23 percent selenium losses from the inventory, casein 41 percent, and gluten 10 percent. The researchers presently conclude that by determining the optimum environment for conditions that stimulate volatilization, it may be possible to manage in-situ selenium removal from seleniferous waters.

Cost estimates for this treatment process are not yet available.

Microbial volatilization of selenium from soils and sediments (C-5). This process is also being studied by researchers at UC Riverside (Frankenberger and Thompson-Eagle, 1988). The study is focusing on optimizing

the dissipation of soil selenium through microbial volatilization as a technique to detoxify Kesterson Reservoir.

The investigators found that the addition of pectin considerably enhanced methylation; about 9 percent of added selenium was recovered in the volatile form after 13 days of incubation following pectin addition. The addition of trace elements such as molybdenum, mercury, chromium, and lead inhibits volatilization, while addition of arsenic, boron, and manganese has little effect. Cobalt, nickel, and zinc in moderate to high levels can dramatically stimulate selenium volatilization, while high nitrogen applications with added carbon inhibit the reaction.

The rate of selenium volatilized depends on the selenium concentration, soil type, selenium speciation, and carbon amendments. Volatilization rates without the addition of carbon were up to an order of magnitude higher with selenite as compared to selenate. Carbon addition in the form of pectin accelerated selenium volatilization 2- to 130-fold. Rates were more pronounced with selenate. Therefore, with carbon amendments, volatilization was almost as rapid for selenate as for selenite. With three pectin amendments over 118 days, total selenium volatilization ranged from 11.3 to 51.4 percent.

Environmental factors were also studied. The optimum buffer pH was found to be 8, while the optimum moisture content appears to be at field capacity. Field moisture capacity is the percentage of water remaining in a soil 2 or 3 days after having been saturated and after free drainage has practically ceased. Warm temperatures enhance the methylating activity--about 17.8 times greater at 35 ^{o}C than at 5 ^{o}C.

Specific carbohydrates and amino acids were found to stimulate methylation. Glucose, sucrose, maltose, fructose, cellobrose, chitin,

galacturonic acid, and methionine promoted selenium methylation. Of all the compounds tested, protein (e.g., casein, albumen, and gluten) enhanced methylation more than any other treatment.

Biomethylated selenium is principally emitted as dimethylselenide (DMSe). Raabe and Al-Bayati (1988) at UC Davis conducted a toxicity study of DMSe in adult rats. The study indicated that inhaled DMSe is nontoxic to adult rats at ambient concentrations of up to 8,034 ppm in exposure periods of 1-hour duration.

Physical and Chemical Processes for Removal of Selenium

Geochemical immobilization (C-6). Neal and Sposito, UC Riverside (1988), studied in-situ attenuation of selenium in irrigated agricultural soils. Studies were conducted on the effects of solution composition on the movement of selenium in the soil profile to identify conditions and mechanisms that may be influencing selenium behavior in irrigated soils.

They reported that the mechanism that immobilizes selenium is affected by the presence of nitrate in soils and waters and causes redox conditions which favor the existence of selenate, one of the mobile forms of selenium. An oxidation-reduction potential sufficiently low for selenate reduction to a less mobile form will not occur if nitrate is present--because the initial supplier of oxygen to a reaction will be the nitrate.

The investigators concluded that the movement of selenium in soils is significantly affected by the chemical environment. Selenium movement was affected by the addition of amendments, which may be responsible for maintaining a chemical environment favorable to particular selenium species.

Iron filings (C-7). Harza Engineering Company conducted selenium removal field studies with iron filings in a small pilot plant at Panoche Drainage

District in 1985 (Harza, 1986). A process based on physical adsorption of heavy metals in iron filings was used.

Field tests showed that hardening of the bed of iron filings creates a problem that could affect the effectiveness and/or the cost of the process. Harza estimated that, with a 2-year adsorbent bed life, 50-percent selenium removal efficiency would cost about $160/acre-ft, while 75-percent removal efficiency would cost about $285/acre-ft. With a 5-year adsorbent bed life, treatment costs would drop to about $70/acre-ft for 50-percent selenium removal efficiency and $120/acre-ft for 75-percent efficiency. Costs for land and disposal of spent iron filings and adsorbed selenium are not included.

Ferrous hydroxide (C-8). The USBR's Engineering and Research (E&R) Center has investigated a process that entails removal of selenate in an oxidation-reduction reaction followed by adsorption of selenite and/or elemental selenium onto iron-oxide particles (Moody et al., 1988). The selenium-rich iron-oxide particles would then be separated from the selenium-free water by gravity settling or, if the iron oxide is sufficiently magnetic, by a magnetic separator.

Bench-scale laboratory experiments indicate that the ferrous hydroxide also removes dissolved oxygen, nitrate, and heavy metals, including chromium and nickel. However, dissolved oxygen and high nitrate concentrations (100 to 600 ppm as NO_3) react with significant amounts of ferrous hydroxide. The investigators report that dissolved oxygen may be removed more economically with pretreatment than with ferrous hydroxide. They expect a prohibitively high cost for the removal of high concentrations of nitrate with ferrous hydroxide. They believe that it may be possible to operate the ferrous hydroxide-selenate reaction at conditions that avoid the oxidation of ferrous hydroxide by nitrate; however, the process cannot presently be recommended for

treating waters with high nitrate concentrations (many west-side drainage waters). For such waters, it may be more economical to lower the concentration of nitrate with pretreatment such as biological denitrification for removing both nitrate and dissolved oxygen. Evidently, nitrate removal is a major consideration in the ferrous-hydroxide process.

The investigators conclude that the estimated costs for the chemical reduction and removal of selenate from inflow water would range from $70 to $182/acre-ft, depending on the composition of the waters and not including the cost of sludge disposal. The total treatment cost for waters with high levels of nitrate would range from $200 to $250/acre-ft, not including sludge disposal.

Ion exchange (C-9). The ion-exchange process is mentioned previously (C-1) as a process that was included in anaerobic-bacterial treatment for purposes of "polishing" treated drainage water to remove boron and selenium. The use of selenium-selective resins to treat raw drainage water has been investigated by Boyle Engineering Corporation. Compared to use in polishing, treatment of raw water with resins has proven to be relatively ineffective because of the difficulty of producing a resin that selects selenium in preference to the sulfate ion abundant in most untreated drainage water in the valley. Boyle (1986) conducted laboratory column tests on drainage-water samples and reported that two strong-base anion resins, both similar to commercial-type resins, showed moderate selectivity for selenate ion over sulfate ion. Studies have not been conducted to demonstrate field-scale reliability and cost estimates.

Reverse osmosis to remove salts and contaminants (C-10). Reverse osmosis is a versatile treatment process capable of removing salts as well as trace-element contaminants. It is also a costly process. A proven technology, its

applicability for valley treatment was examined by CH2M Hill (1986) in an appraisal study to treat drainage water from the San Luis Drain. The lengthy operating history for the process has produced reliable assessments of operating, maintenance, and waste-disposal requirements and costs. The presence of relatively high concentrations of sulfate, calcium, and silica in the drainage waters of the west side would require more elaborate pretreatment and higher costs than are generally reported in the research literature. Treatment process wastes probably would require very expensive Class-I disposal ponds under California hazardous-waste disposal laws. Despite designing for the highest practicable water recovery rate (e.g., the lowest volume of waste), provision for disposal of wastes was found to increase reverse-osmosis treatment costs by 50 percent. Process waste brine from a 10-Mgal/d plant would contain a TDS concentration of 73,000 ppm, including selenium at 2.58 ppm. Annual accumulation of salts would be about 113,000 tons.

CH2M Hill reported that the treatment cost (including intake facilities and regulating reservoir) of reducing salt concentration from 10,000 ppm TDS to 550 ppm TDS would be about $1,090/acre-ft of inflow water. Waste-disposal requirements could increase this by $560/acre-ft. Resale of product (treated drainage) water and of waste brine salts could result in a slightly lower net treatment cost. In the treated drainage water, selenium concentration would be reduced by about 95 percent, to 10-20 ppb. Though reduced from the inflow amount, boron concentrations would remain at 7-8 ppm, restricting use of the treated drainage water to crops highly tolerant of boron. The potential for drainage-water reuse is discussed in greater detail later in section D of this chapter.

The California Department of Water Resources began operation of its Los Banos desalting demonstration plant in the fall of 1983 and ceased the operation in August 1986. It concluded that additional work is required on the pretreatment system to establish the feasibility of a State Water Project desalting facility.

Generate electric energy and heat for desalinization with a cogeneration process (C-11). There is considerable interest in the San Joaquin Valley in the concept of making dual use of thermal energy for electrical-energy generation and for desalinization of drainage water by vaporization. Feasibility depends on some key factors such as the value of the electrical energy generated, cost of fuel, and air-quality restrictions. Desalted water will have some value, but experience with present vaporization technology indicates that amortization of the capital cost of equipment, which would be exclusive of energy costs, could approach $1,500/acre-ft. Westlands Water District has funded a cogeneration study by Resources Management Institute. Results of the study are expected to be available later in 1989 and will enable a better evaluation of this option.

DRAINAGE-WATER REUSE (D)

Drainage water potentially could be reused in several ways and for different purposes, including: (1) Agriculture, (2) fish and wildlife, (3) powerplant cooling, (4) solar ponds for energy production, (5) recovery and sale of salts from evaporation ponds, and (6) aquaculture.

Reuse subsurface drainage water for agriculture (D-1). Field experiments by the U.S. Salinity Laboratory (Rhoades, 1987) and others (CDFA, 1988) have shown that crops such as cotton, eucalyptus trees, and atriplex (saltbush) can be grown using drainage waters. The upper tolerance limits of TDS in

irrigation water for these crops are 3,000, 10,000, and 20,000 ppm, respectively. Leaching of salts from the root zone is required, however, in order to maintain a favorable salt balance.

Blending of drainage water with freshwater and reuse of the mix for irrigation is a common practice throughout the drainage problem area in places where drainage disposal opportunities are limited; e.g., where a river or drainage canal is not available. Where this has been the practice over a number of years without provision of an outlet for leached salts (as in Broadview Water District during 1977-82 [pers. comm., Daniel Nelson, Broadview Water District, Firebaugh, CA, 1987]), a significant reduction in crop diversity and productivity resulted. Similar results would be expected in other areas where a drainage outlet is lacking.

In a drainage reuse practice recommended by Rhoades (1987), freshwater is used in preirrigation to leach salts from the root zone sufficiently to establish the young plants. Preirrigation is then followed by the use of unblended subsurface drainage water. This reuse option reduces the freshwater irrigation requirement but still necessitates an effective drainage disposal method.

The value and marketability of trees as a fuel supply and as wood pulp for paper production are being evaluated by the CDFA. Saltbush is a forage crop similar to alfalfa. Its value as an animal-feed product is also being evaluated by the CDFA.

Eucalyptus trees create new wildlife habitat in the otherwise nearly treeless valley. Preliminary findings from wildlife studies being conducted by CSU Fresno show that wildlife species such as mourning doves, ring-necked pheasants, blacktailed jackrabbits, desert cottontails, raptors, songbirds,

foxes, and coyotes use the eucalyptus stands (pers. comm., D. L. Chesemore, California State University, Fresno, Fresno, CA, 1988).

Although eucalyptus and saltbush plantings create the potential to enhance wildlife and provide agricultural income, the presence of high selenium concentrations in the drainage water used to irrigate these crops presents the potential for selenium bioconcentration in the environment and resultant injury to wildlife using this habitat. Studies are being conducted to determine potential contaminant hazard of agroforestry sites to wildlife.

Use for fish and wildlife (D-2). See option F-11.

Use for cooling water for fossil-fueled power generation plants (D-3). Use of drainage water for powerplant cooling was an important element of the recommended plan of the Interagency Drainage Program (1979). However, the energy supply and demand conditions of the 1970's, and the subsequent energy planning strategies, have changed significantly (California Energy Commission, 1985). There are currently no plans for major thermal powerplants in the valley. Moreover, treatment costs would be at least $250/acre-ft to make drainage water acceptable for powerplant cooling (DWR/UC, 1978; Loughlin, 1984). If a demand for drainage water for powerplant cooling does develop in the future, its use for cooling would likely be at a cost to the draining entities, rather than at a profit as earlier anticipated.

Use in solar ponds to concentrate heat for production of electrical energy (D-4). Nonconvective solar-gradient ponds can produce electrical energy. In studies conducted at Los Banos, DWR has succeeded in producing a stratified pond that attained temperatures in the heat storage zone in excess of 175 ^{o}F, and generated electricity in a 10-kilowatt (kW) turbine generator. Brine in the pond was produced from salts having chemical characteristics similar to concentrated drainage brine (SJVDP, 1988a). If fuel-oil costs

reach about $30/barrel, solar ponds may become competitive with conventional electrical-energy sources.

In a USBR E&R Center (1983) study of solar ponds, it was estimated that the levelized bus-bar energy cost for baseload operation of a 50-megawatt (MW) powerplant would be 100 mills/kilowatthour (kWh) (1982 costs). This is the cost of energy at the site where the energy is generated, as opposed to the site where energy is delivered to the consumer. Accordingly, the bus-bar cost does not account for energy transmission losses and costs. This is lower than the projected cost of baseload power in Northern California. By contrast, the Massachusetts Institute of Technology (1983) in a report to the Electric Power Research Institute estimated that the levelized bus-bar cost of energy for a 50-MW solar-pond system at the Salton Sea would be about 353 mills/kWh (1983 costs). From those and other studies, it appears the range of net costs for a 50-MW baseload plant for disposal of drainage water into solar ponds would be $250 to $710/acre-ft.

<u>Recover and sell salts from evaporation ponds (D-5)</u>. URS Corporation (1987), in a study for Westlands, has reported that successful merchandising of salts from drainage water, primarily sodium sulfate, would be unlikely because there is a weak market for the product. To interest the pulp and paper industry, the salts would need to be refined to 99.5-percent purity. URS did not believe this level of purity was "economically attainable," so the value of a less pure (90-98 percent) salt was also evaluated. This was reported to cost $90/ton to produce and would sell for about $36/ton, if a market could be found. When considered in isolation, commercial salt reclamation from agricultural drainage water is not a profitable enterprise. However, recovery and sale of such salts may be economically justified as part

of a larger drainage management/disposal system, especially when compared to the expense of disposal at Class I sites.

EPOC AG (1987), as well as others, did not agree with URS on the recovery and marketability of salts in drainage water. EPOC AG reported that in treatment schemes employing boron removal and a solar salt works for disposition of the treated water, byproduct salts (especially sodium sulfate decahydrate or Glaubers salts) can be recovered and sold to defray treatment costs. The consultant added that the pilot salt works at Murrieta Farms and the solar ponds at DWR's Los Banos desalting facility both demonstrated that sodium sulfate can be produced at the required purity. Murrieta Farms tests showed that the salt was not contaminated with selenium or sodium chloride.

Further studies need to be conducted with respect to salt harvesting and marketing.

<u>Use in an aquaculture system (D-6)</u>. Aquaculture studies (Brown, 1987) have demonstrated that drainage water can be used to culture a wide variety of organisms varying from fish to algae. However, a full assessment of the potential of aquaculture requires an evaluation of the marketability of products grown in drainage water. A concern important to marketability is the concentrations of potentially toxic trace elements in harvested biota. There is little likelihood that drainage water could be used as a culture medium in traditional aquaculture.

DRAINAGE-WATER DISPOSAL (E)

A total of nine drainage-water disposal options have been identified, which include or involve: (1) Discharge to the San Joaquin River, with and without dilution, (2) use of the San Luis Drain, (3) evaporation ponds, (4) disposal or injection into ground water or ground-water depressions,

(5) injection into deep geologic formations, and (6) reuse for irrigation on the east side of the valley.

<u>Discharge drainage water to the San Joaquin River without dilution (E-1)</u>. Drainage water from the Northern and Grasslands Subareas is currently being discharged directly and indirectly to the San Joaquin River without treatment and without additional dilution water. For planning purposes, it is assumed that this can be continued if the water-quality objectives for the receiving waters are met. The State-proposed objectives for the San Joaquin River are shown in Table 2-8. On the basis of present drainage-water quality characteristics, it is estimated that most of the land in the Northern Subarea and about half the land in the Grasslands Subarea (where drainage is necessary) could be drained directly into the river.

<u>Discharge drainage water to the San Joaquin River with dilution (E-2)</u>. It is possible that drainage water above that which can presently be assimilated by the San Joaquin River may be discharged to the river and still meet water-quality objectives, if sufficient dilution is provided from a freshwater source such as the Delta-Mendota Canal or the California Aqueduct. Drainage water could be mixed with the dilution water in one of the canal wasteways, such as Newman Wasteway, prior to discharge to the river. Preliminary analyses show that the current cost of dilution water would become prohibitive for drainage water with selenium concentrations above 50 ppb. Changing policy by the SWRCB suggests that the use of freshwater for dilution of poor-quality water may be considered an "unreasonable use" of water, unless it occurs as an adjunct of providing water to another beneficial use; e.g., fish and wildlife.

Compared to the Northern Subarea, the applicability of the dilution option in the Grasslands Subarea is limited because the majority of the

drainage water contains selenium in excess of 50 ppb, TDS in excess of 5,000 ppm, and boron in excess of 10 ppm. The volume of drainage water discharged to the river will depend on the river's assimilative capacity at the time of discharge.

Clean, modify, extend, and use the San Luis Drain to transport drainage water from Highway 152 to the San Joaquin River (E-3). The San Luis Drain north of the Mendota Pool could be used to convey freshwater to the Grasslands Subarea and drainage water from South Mud Slough (near Highway 152) to the north end of the Kesterson Reservoir site. From there, drainage water would flow into North Mud Slough and then the San Joaquin River. The use of the drain in this manner is commonly referred to as the "Zahm-Sansoni-Nelson Plan." Cleanup of the drain from Kesterson Reservoir to Bass Avenue at Mendota is estimated to require removal and disposal of about 147,000 cubic yards of mostly windblown sediments. The plan would keep drainage water out of many of the natural and manmade water channels in the Grasslands area, thus protecting fish and wildlife in those areas from continued exposure to drainage water contaminants.

A variation of the Zahm-Sansoni-Nelson Plan is being proposed by Panoche Drainage District, Firebaugh Canal Water District, Broadview Water District, Pacheco Water District, Charleston Drainage District, and a portion of the Central California Irrigation District (from a March 1989 briefing paper, "Use of the San Luis Drain for Conveyance of Drainage Water"). In this proposal, drainage water would be discharged into the San Luis Drain starting about 1.5 miles east of Fairfax Avenue. Drainage water would be conveyed in the drain to its northerly terminus near Mud Slough (about 34 miles), and from there down Mud Slough about 6 miles to the San Joaquin River. The districts have made a formal request to the USBR for use of the drain.

This option could also include extending the drain 6 miles from the north end of the Kesterson Reservoir into Newman Wasteway, or beyond, thus protecting Mud Slough and a portion of the San Joaquin River from drainage-water degradation. The extension would also provide an opportunity to dilute drainage water with releases from the Delta-Mendota Canal as discussed in option E-2. Extension of the San Luis Drain at its current conveyance capacity would cost about $2.1 million/mile.

Clean and use the San Luis Drain south of Mendota to convey drainage water (E-4). This option would require cleaning and using the San Luis Drain (south of Mendota Pool) to convey drainage water within Westlands Water District. This would be coupled with drainage-water treatment and disposal sites to be located in the vicinity of the drain. Cleanup of the drain from Bass Avenue in Mendota south to Mt. Whitney Avenue would require removal and disposal of about 64,000 tons of mostly windblown sediments.

Evaporate drainage water in ponds (E-5). Evaporation ponds have provided the principal means for drainage-water disposal in the Tulare and Kern Subareas. There are 27 evaporation ponds in the San Joaquin Valley, ranging in size from 8 to 1,890 acres and totaling about 7,400 acres. All but 300 acres of the ponds are in the Tulare Basin (Tulare and Kern Subareas). Pending applications and plans for new ponds would increase the area by 10,000 to 20,000 acres (Westcot et al., 1988).

Evaporation ponds in the valley require a waste discharge permit, and they are regulated by the CVRWQCB under waste discharge requirements which, beginning in 1988, include conditions recommended by the California Department of Fish and Game stipulating construction and operation guidelines. The guidelines, spelled out in individual cooperative agreements (monitoring and mitigation agreements) between DFG and pond owners/operators, include:

(1) Removal of vegetation and organic matter prior to construction and filling (and maintenance to keep ponds free of vegetation), (2) construction of levee slopes as nearly vertical as possible (2:1 if possible--which could require hardening the slopes with concrete or other materials), (3) maintenance of the pond depths at 2 feet or greater, (4) filling and draining of ponds as rapidly as possible, and (5) hazing birds from the ponds when selenium levels in aquatic invertebrates (common food items for aquatic birds) exceed 4 ppm (dry weight).

The agreements between DFG and pond owners/operators stipulate compliance with the California Environmental Quality Act (CEQA). In that regard, beginning in 1989 the pond permit process will include development of mitigation actions (being developed jointly by DFG/CVRWQCB) required to offset cumulative adverse impacts on fish and wildlife resources, especially aquatic birds, resulting from ponds contaminated with elevated concentrations of toxic trace elements. These actions will probably require development of uncontaminated alternative wetland habitats adjacent to evaporation ponds, including a firm, adequate supply of "clean" water.

Costs of constructing evaporation ponds in the past have ranged from $1,500 to $2,500/acre if done by a drainage district. Costs could range from $6,000 to $10,000/acre if done by a private contractor (USBR, 1984 estimate). However, new construction and operation guidelines would likely increase costs.

Studies by the U.S. Fish and Wildlife Service (Ohlendorf, 1988; Skorupa, 1989) have found that, of the 12 ponds studied to date, 7 ponds (representing approximately 75 percent of the valley's pond acreage) show significantly elevated frequencies of adverse biological effects in migratory waterfowl. (See F-3.) Except at one pond, these effects appear to be related to unsafe

levels of selenium. Potential methods to reduce wildlife contamination include screening to prevent access, or treating pond waters to remove food-chain organisms. However, these methods have not been field tested and may prove ineffective or too expensive for application. In view of the potentially escalating costs of operation and threats of contamination to wildlife, it may be prudent in some areas to retire land from irrigation.

Transport and dispose of drainage water into shallow ground-water aquifer depressions (E-6). This option involves the irrigation of salt-tolerant trees (e.g., eucalyptus) in the westerly portion of the valley where there is a reverse gradient of the water table in the semiconfined aquifer (see Figure 1-2), which creates a depression in the water table adjacent to the Coast Range. Drainage water might be disposed of here after its reuse in irrigation of salt-tolerant trees.

The principal merit of the concept is the relatively convenient disposal of drainage water while producing potentially marketable wood products (i.e., firewood or biomass). Significant drawbacks, however, include the cost of transporting drainage water uphill from the drained areas and probable degradation of ground water in the semiconfined and confined aquifers.

Inject drainage water into the saline ground water underlying the zone of freshwater (E-7). The base of the fresh ground-water zone is about 2,500 feet below ground surface and is underlain by saline water to an undetermined depth. Injection of drainage water into this underlying saline water zone is a potential disposal alternative. Drainage water or evaporatively concentrated brines could be injected under pressure into relatively permeable geologic strata for disposal at depths of 3,000-3,500 feet below ground surface.

This option has not been explored in any detail because of the potential for migration of the drainage water into aquifers which contain usable ground water. EPA's regulatory requirements prohibit injection of wastewater into ground water containing less than 10,000 ppm salinity, and require that injected wastes be effectively isolated from "usable sources of ground water" (defined as ground water containing less than 10,000 ppm salinity).

Inject drainage water into deep geologic formations (E-8). URS conducted an appraisal-level study of this option, examining the possibility of injecting 5-10 Mgal/d of drainage water from the San Luis Drain into deep geologic formations (1986). According to URS, the drainage water would not be classified as hazardous waste, and it would be permissible to inject such water through triple-cased wells into a highly saline formation underlying the Kreyenhagen formation, an areally extensive, impermeable formation located approximately 5,000 feet below the land surface. The injection cost (including well construction, rapid filtration pretreatment, and annual operation and maintenance was estimated to be about $190/acre-ft. That estimate, however, was based on many uncertainties, and URS cautioned that pilot testing would be necessary to evaluate technical feasibility, costs, and institutional acceptability. Consequently, a pilot-testing program to inject drainage water to a depth of 7,000 feet is being conducted near Mendota by URS for Westlands Water District. This program should provide a more reliable cost estimate and feasibility assessment of deep-well injection.

Transport drainage water to east side of valley for reuse on irrigated lands (E-9). Much of the east side of the valley is reported to have a problem of slow rate of infiltration of irrigation water through the soil and down to root zones due, in part, to the lack of sufficient electrolytes or dissolved mineral salts. Commonly, gypsum is added to the east-side

irrigation waters to increase the soil infiltration rate. The east side is also selenium-deficient, and selenium is commonly provided to livestock as a feed supplement. It has been suggested that importation of west-side drainage waters might help alleviate both the selenium-deficiency and water infiltration-rate problems on the east side.

Some preliminary studies are being conducted by the SJVDP to examine potential impacts to be considered and to determine if the concept merits further investigation. Present indications are that, long-range, the sodium, boron, and chloride content of the west-side drainage water could adversely affect east-side crops (SJVDP, 1989). Drainage water would be blended with east-side irrigation water, and boron is expected to be the drainage-water constituent that would limit or determine the acceptable drainage-water:east-side blending ratio. To obtain the desired blending ratio, the volume of drainage water transported to the east side is expected to be limited to between 30,000 and 60,000 acre-ft/yr. Conveyance cost from the vicinity of Tranquility to the Friant-Kern Canal northeast of Clovis would be about $300/acre-ft for 30,000 acre-ft/yr and $230/acre-ft for 60,000 acre-ft/yr.

FISH AND WILDLIFE MEASURES (F)

Fish and wildlife measures have been developed which address the Drainage Program's goal to "protect, restore, and to the extent practicable improve fish and wildlife resources of the San Joaquin Valley." Options briefly discussed in this section include actions that could be undertaken in concert with other options discussed in this chapter as well as actions that are designed to solely address drainage-related fish and wildlife problems. This discussion is organized according to fish and wildlife objectives

for: (1) Protection, (2) restoration, (3) substitute water supplies, and (4) improvement.

Protection of Fish and Wildlife Resources

Planning, environmental assessment, and mitigation (F-1). A number of procedural actions can be taken that could help protect existing fish and wildlife resources from adverse impacts that may be created by future projects to manage drainage water. Those procedural actions are defined in a variety of Federal and State laws, executive orders, regulations, guidelines, and policies which address consideration of environmental values (including fish and wildlife resources) in planning public projects (especially water resource projects) or private projects requiring government permits. Examples of such laws include the: National Environmental Policy Act, California Environmental Quality Act, Fish and Wildlife Coordination Act, Endangered Species Act, and California Endangered Species Act.

More aggressive implementation or enforcement of these laws, amendments to these laws, and/or the passage of new planning, environmental assessment, and/or mitigation laws could increase protection for fish and wildlife from impacts associated with the production, storage, discharge, and/or other management of drainage water. Existing laws could be more aggressively implemented or enforced by increasing the number of natural resource personnel, and funding for such personnel and biological impact studies in action and regulatory agencies. Existing laws could be amended by specifying that all adverse environmental impacts of development projects be fully compensated for, that the costs of that compensation be paid for by project beneficiaries, and that all such costs be fully accounted for in project benefit-cost analyses prior to any project approvals. New laws could be passed that would require, for example, that all potentially affected fish and

wildlife habitats be fully compensated for prior to the occurrence of any such impacts.

Existing planning, environmental assessment, and mitigation laws, regulations, policies, etc. are primarily procedural in nature. Although they require consideration of environmental effects in preproject planning and analysis, they do not mandate that environmentally sound decisions be made. Therefore, although full compliance with such procedural requirements may increase the likelihood that fish and wildlife resources will be protected, they do not guarantee it.

The principal advantages associated with new or strengthened planning, environmental assessment, and mitigation laws, regulations, policies, etc. would be: more complete cost accounting (internalization of costs) for proposed projects, and increased protection for fish, wildlife, and their habitats from drainage-related impacts. Principal disadvantages of this option include: no protection for fish and wildlife resources that are now or in the past have been affected by drainage-related impacts, and increased up-front costs for new projects.

Regulation of take of fish and wildlife (F-2). Many of the lands which support fish and wildlife habitats in California are privately held; however, waters, fish, and wildlife in California are resources owned in common by all the people. The use of those resources, including the take of fish and wildlife, is regulated by Federal and State laws, regulations, and policies.

The principal laws and regulations which currently provide the legal bases for managing the take of fish and wildlife include the: Migratory Bird Treaty Act, Endangered Species Act, California Endangered Species Act, and other provisions of the Fish and Game Code of California. More aggressive enforcement of existing laws and amendments and/or the passage of new laws

that prohibit or otherwise regulate the take of fish and wildlife might increase protection for fish and wildlife from the impacts of drainage water. More aggressive enforcement of existing or new laws would require additional funding and personnel in enforcement agencies. Existing laws could be amended by, for example, eliminating exceptions to provisions prohibiting take, adding provisions for citizen suits, adding provisions to Federal laws for awards to citizens for assistance in discovering violations and/or prosecuting offenders (e.g., like the CDFG CALTIP Program), and increasing penalties for violations. New laws could be passed that would provide protection for a broader range of fish and wildlife species (i.e., species in addition to migratory birds, endangered species, and game species of fish and wildlife) and their habitats.

As an example, the Migratory Bird Treaty Act prohibits the unlawful take of migratory birds. Lawful take usually requires a special government permit which can allow take, for example, in the conduct of biological research, in accordance with hunting regulations, or to protect agricultural crops from bird depredations. Migratory birds are defined by international treaty and Federal regulations, and include almost all those species (including, for example, waterfowl, shorebirds, and wading birds) that regularly use the new wetland-aquatic habitats in the San Joaquin Valley that have been created by drainage-water evaporation ponds. Avian reproduction and survival studies conducted at several of those ponds have clearly documented significantly increased frequencies of embryo deformities, reduced egg hatchability, and reproductive failure (Ohlendorf, 1988; Schroeder et al., 1988; Skorupa, 1989; Skorupa and Ohlendorf, 1989; Skorupa and Ohlendorf, 1988). Except at one pond, the effects appear to be related to toxic concentrations of selenium. Selenium is carried into evaporation ponds by subsurface agricultural drainage water.

These adverse biological effects on migratory birds might be construed as takings under the Migratory Bird Treaty Act. They are not legally permitted takings and conceivably could be prosecuted as violations of that Federal law. Penalties for violation of the act include fines, imprisonment, and forfeiture of property. The Secretary of the Interior may exercise prosecutorial discretion in enforcing the act.

If evaporation pond owners/operators were found guilty of violating this law and severe penalties were imposed, such actions might provide the necessary incentives to encourage others to close toxic ponds, eliminate wildlife access to toxic drainage waters, and/or treat the waters to render them nontoxic. In light of the penalties associated with violation of this and similar wildlife protection laws, a far-reaching education and information program combined with rigorous enforcement efforts has the potential to discourage drainage management practices that could harm some species of fish and wildlife. Drawbacks of using these laws include: protection for only selected groups of fish and wildlife (i.e., migratory birds, endangered species, and game species), the potential creation of a political backlash and pressures to weaken the acts, and the potential for increased costs to farmers associated with management of drainage water.

Representatives of the agricultural community have been advised that ongoing operation of some evaporation ponds may violate the Migratory Bird Treaty Act and that the proposed expansion of existing or construction of new ponds has the potential to trigger the Endangered Species Act.

<u>Regulation of land and water uses (F-3)</u>. Some uses of lands and waters in California are regulated by public agencies (subject to applicable Federal and State laws) to ensure that those uses do not harm other private properties or public resources. For example, the development and operation of

evaporation ponds as drainage-water disposal facilities are regulated under the Porter-Cologne and Toxic Pits Cleanup Acts, among other reasons, to ensure that substances held in those ponds do not pollute underlying ground waters or adjacent lands or surface waters, or create a nuisance. As was pointed out by the SWRCB in their Kesterson Reservoir cleanup order, nuisance can include a nuisance to public health created by the contamination of game birds (SWRCB, 1985). More aggressive enforcement of existing regulatory programs, amendments of existing laws and/or regulations, and/or the development of new laws, regulations, and associated programs that more specifically regulate the management of agricultural lands, irrigation water, and/or drainage water (and associated facilities) could increase protection for fish and wildlife from impacts related to drainage water.

Subsurface drainage water is produced as a result of percolation of irrigation water below the crop root zone. In order to produce crops and prevent salinization of soils, farmers on the west side of the valley must apply enough water to satisfy plant needs and a small additional amount to leach salts deeper into the soil profile. In part, Article X, Section 2, of the California Constitution prohibits waste or unreasonable use of water. It could be determined that agricultural use of public irrigation waters in excess of crop water requirements plus a minimal leaching fraction constitutes violation of the State's constitution. This finding could provide grounds for a water-use regulatory program, the results of which could be improved management of irrigation and a significant reduction in the production of drainage water, hence a reduction in contaminant threats to fish and wildlife. The CVRWQCB has suggested that such a program could be used as one tool to address drainage problems in the San Joaquin Basin by withdrawing permission to irrigate specific agricultural lands (CVRWQCB, 1988a). Prior to

implementation of such a regulatory program, it would be necessary to ensure that the waste/minimal leaching fraction threshold was established at a level that was sustainable (so that soils did not become salinized), technically attainable, and acknowledged differences in soil characteristics.

Evaporation ponds are widely used throughout the San Joaquin Valley for disposal of drainage water. Evaporative concentration increases waterborne concentrations of some drainage-water contaminants (Tanji, in press). In addition, through bioconcentration and possibly biomagnification, aquatic plants and animals can accumulate tissue concentrations of some drainage contaminants two to three orders of magnitude greater than that in the water (Barnum and Gilmer, 1988; S. A. Ford and D. K. Hoffman-Floerke, DWR, Sacramento and Fresno, CA (unpublished data); T. Heyne, CSUF, and M. Kie, CDFG, Fresno, CA (unpublished data); Schroeder et al., 1988; White et al., 1987). Adverse biological effects upon aquatic birds (especially waterfowl and shorebirds) that use some evaporation ponds are well documented (Ohlendorf, 1988; Schroeder et al., 1988; Skorupa, 1989; Skorupa and Ohlendorf, 1989; Skorupa and Ohlendorf, 1988; pers. comm., Apr. 18, 1989, J. P. Skorupa, USFWS-PWRC, Davis, CA).

Current general regulations affecting the siting, design, construction, and/or operation of evaporation ponds could be changed to more specifically require that those ponds: (1) Be sited, designed, constructed, and operated to minimize their attractiveness to wildlife, (2) be covered, netted, or otherwise screened to preclude access by wildlife, (3) receive, store, and evaporate only treated, saline waters, and/or (4) be decontaminated or closed if it is determined that they have harmed wildlife or contain concentrations of contaminants in water, sediments, or wildlife food-chain organisms in excess of safe levels.

One specific example of a regulatory change that would likely result in increased wildlife protection would be the requirement that pond owners/operators acquire, develop, and manage wetland and/or aquatic habitats in the vicinity of hazardous evaporation ponds as one condition of operating such ponds. The acquisition and development of new aquatic-bird habitats (complete with adequate, firm supplies of clean freshwater) would be expected to partially mitigate for some of the harm currently being experienced by wildlife exposed to toxic concentrations of contaminants in some valley ponds. This additional measure of protection would occur because high-quality wetland and aquatic habitats would be expected to preferentially draw some wildlife away from evaporation ponds, and also provide a safe haven for birds hazed off of ponds. Potentially, the numbers of birds exposed to drainage-water contaminants, their exposure frequencies and/or durations, and related biological effects would all be reduced.

There are several advantages and potentially some disadvantages associated with regulation of land and/or water uses to minimize or avoid fish and wildlife impacts caused by production and discharge of agricultural drainage water. Such regulation shifts the costs associated with environmental damages from the public at large to the pollutant producer. Such regulations would likely result in increased water-use efficiency and reduced agricultural water demand, potentially freeing up conserved water for allocation to other beneficial uses such as fish and wildlife. Disadvantages include: an increase, at least initially, in farmers' operating costs; increased costs to the public associated with the regulatory process and associated bureaucracy; and a delay in the actual reduction of pollution and associated adverse biological effects. In addition, because they are direct management regulations and not "performance standards," they would have to be

carefully crafted to avoid reducing farmers' flexibility in satisfying the regulatory requirements.

Water-quality control (F-4). A number of direct and indirect actions could be taken that together could ensure protection of fish and wildlife resources from adverse impacts associated with agricultural drainage water. Direct actions could include direct regulation, for example, through the establishment of maximum drainage discharge volumes and/or qualities (i.e., loads and/or contaminant concentrations) or through the establishment of water-quality standards for receiving waters. Indirect means could include financial incentives; for example, by charging farmers drainage fees equal to the costs of environmentally safe treatment and disposal or by significantly reducing or eliminating public subsidies on irrigation water. Farmers would likely respond to such water-quality control requirements by conserving irrigation water, reducing the production of drainage water (e.g., through source control), and/or treating and/or diluting drainage waters prior to discharge into surface waters.

The CVRWQCB (1988b) has proposed a water-quality control basin plan amendment directed at problems associated with drainage water generated in the Grasslands area of the San Joaquin Basin. Questions have arisen regarding whether the proposed amendments will satisfy State and Federal legal requirements and/or whether they provide adequate protection for beneficial uses (including fish and wildlife) in the San Joaquin River and tributaries.

There are several advantages and potentially some disadvantages associated with the use of water-quality control regulations to minimize or avoid fish and wildlife impacts caused by production and discharge of drainage water. Regulation of water quality shifts the costs associated with environmental damages from the public at large to the land owner/operator.

Because they are "performance standards" and don't necessarily dictate land and water-use management practices, they provide the land owner/operator with flexibility. It is likely that water-quality control regulations would encourage better on-farm stewardship of land and water resources, because to date source control appears to be the single, most cost-effective action to control the volume of drainage produced. On-farm water conservation could potentially free up conserved water for allocation to other beneficial uses such as fish and wildlife. Disadvantages include: an increase, at least initially, in farmers' operating costs; increased costs to the public associated with the regulatory process and associated bureaucracy; and a delay in the actual reduction of pollution and associated adverse biological effects.

Restoration of Fish and Wildlife Resources.

Flooding and flushing with freshwater (F-5). One method to decontaminate and restore drainage-polluted fish and wildlife habitats (especially aquatic and wetland habitats) involves flooding and flushing with uncontaminated freshwater. Introduction of replacement or dilution freshwaters to contaminated habitats would immediately reduce the concentrations of contaminants to which fish and wildlife are exposed and should ease the health stresses that such organisms may be experiencing. In flowing aquatic systems, natural biogeochemical processes would continue slowly releasing water-soluble chemical forms of drainage contaminants which would be carried downstream. Flooding contaminated wetlands with clean freshwaters should encourage remobilization of selenium (and perhaps other trace elements) and thereby allow leaching of those substances deeper into the soil profile and/or flushing into surface waters with seasonal discharges. Surface flushing in wetlands may also carry suspended sediments and detrital matter which

frequently contain significantly elevated concentrations of some trace elements of concern (e.g., selenium).

Preliminary findings from studies conducted in wetland habitats in the Grasslands area suggest that flooding drainage-contaminated marshes with clean freshwaters can result in fairly swift decontamination of those environments and associated wildlife populations (USFWS-SLNWR, 1988).

Advantages of this decontamination approach include use of conventional, nondisruptive habitat-management practices. One disadvantage (of unknown magnitude) is the temporary discharge of contaminants into surface and ground waters. Another disadvantage is the need for an adequate freshwater supply. Freshwaters for this decontamination technique could potentially originate from any of a number of sources, including reallocation of existing "developed" supplies, water conserved through on-farm management practices, high-quality pumped ground water, and/or diversion of floodflows from the San Joaquin or other rivers in the valley. See "Substitute water supplies for fish and wildlife resources" (options F-11 through F-15) for discussion of other possible water sources.

<u>Soil and vegetation management (F-6)</u>. Direct manipulation of soil and vegetation may provide a means to decontaminate wildlife habitats (especially wetland, grassland, and cropland habitats) that have been degraded by use of drainage water for flooding and/or irrigation. Proposed decontamination actions include burning, discing, fertilization, and plant/soil volatilization. It is believed that burning may extract selenium and perhaps other trace elements currently bound in vegetation and remove them (in volatile or particulate forms) into the atmosphere or with seasonal discharge waterflows. Discing may bury the contaminants deeper into the soil column and/or possibly oxygenate some of them now bound in near-surface soils,

allowing their resolubilization and removal either through deep percolation into the ground water or removal from the site with the flushing of surface soils. Fertilizing may increase populations of algae and bacteria and their uptake and accumulation of trace elements of concern. Removal would probably occur through flushing with discharge flows. Plant/soil volatilization involves initial cultivation of native plants that are able to extract selenium from the soil and volatilize it through their leaves, followed by plowing those plants to provide carbon and selenium for volatilization by soil microbes. See "Microbial volatilization," option C-5.

Soil- and vegetation-management techniques are currently being field tested in the Grasslands area (at Los Banos WA [see DFG, 1987b] and at Kesterson Reservoir [see LBL and Division of Agriculture and Natural Resources, UC, 1989]) to determine their efficacy at habitat decontamination. No data are yet available with which to evaluate the efficacy of these techniques in removing contaminants from affected habitats.

Advantages of these decontamination techniques include use of conventional, nondisruptive habitat-management practices. The major disadvantage (of unknown magnitude) is the temporary discharge of contaminants into surface water, ground water, air, and/or algae and bacteria.

Cultivation and harvesting of selenium-accumulating plants (F-7). See option A-13.

Microbial volatilization (F-8). See options C-4 and C-5.

Geochemical immobilization (F-9). See option C-6.

Sequential implementation of decontamination and restoration (F-10). It may be determined (for scientific, budgetary, or other reasons) that disruptive decontamination techniques (e.g., intentionally cultivating and harvesting selenium-accumulating plants) are the most practicable for use in

some or all of the contaminated habitats in the valley. In light of the current paucity of native habitats in the valley and the resultant high value to resident and migratory populations of fish and wildlife of those surviving habitats, public and private habitat managers will likely view even temporary losses to be unacceptable.

Implementation of disruptive techniques could be staged in a sequential manner such that the net loss of total habitat acreage in the valley is avoided or minimized. Sequential staging could occur within a single wildlife management unit, or new, clean habitat could be developed (e.g., through reclamation of native habitat by conversion of marginal farmlands) and contaminated habitat units of equivalent size could be decontaminated and restored on a sequential basis.

Advantages associated with such measures include retention of current habitat acreage and productivity. Disadvantages include the potential costs associated with acquisition or leasing, and at least temporary management of new lands to make up for lost productivity on those lands undergoing decontamination and restoration.

Substitute Water Supplies for Fish and Wildlife Resources

Reuse of subsurface agricultural drainage water (F-11). Most of the aquatic wildlife-related features of the San Joaquin Valley master drain plan (developed in the late 1960's) relied upon use of subsurface drainage water for wetlands management for wildlife. Pond systems were specifically planned (and in the case of Kesterson Reservoir, actually designed and partially constructed) to both seasonally store flows from the San Luis Drain and serve as waterfowl improvement areas (USBR, 1972).

The tens of thousands of deaths and deformities of aquatic birds and numerous other ecological impacts that occurred at Kesterson Reservoir are

well documented (Beedy, 1987; Hoffman et al., 1988; Ohlendorf et al., 1986a, 1986b, 1988; Schuler, 1987; Williams, 1986). Existing information strongly suggests that those adverse biological effects probably resulted from ingestion of aquatic plants and animals from the reservoir that had accumulated (bioconcentrated and possibly biomagnified) selenium and perhaps other trace elements carried in drainage water (Hoffman et al., 1988; Ohlendorf et al., 1988, 1986a, 1986b; Williams, 1986).

Laboratory and field research have clearly demonstrated that as a result of bioconcentration, and possibly biomagnification, even very low concentrations of waterborne selenium can be readily accumulated to toxic concentrations in tissues of food-chain organisms and consumers at higher trophic levels (such as fish and birds) (Barnum and Gilmer, 1988; Baumann and Gillespie, 1986; Besser et al., 1987; Davis et al., 1988; Eisler, 1985; Gillespie et al., 1988; Lemly and Smith, 1987; Lemly, 1985a, 1985b). This information alone is adequate to suggest that without extensive pretreatment to remove selenium, and perhaps other potentially toxic trace elements, use of most subsurface drainage waters in wetland-wildlife habitats is unjustified. However, drainage water which naturally contains low concentrations of trace elements and/or salts (see discussion elsewhere in this report regarding shallow ground-water/drainage-water quality in the Kings River Delta/northern Tulare lakebed area) or which has been treated to remove trace elements, but retains the salts, may have potential for such uses. In addition, if drainage water was treated to remove both trace elements and salts, and/or was significantly diluted, such water could potentially be used for instream flows for fisheries.

Information regarding the maximum safe concentrations of substances of concern (including salts) in drainage water used for sustainable management of

aquatic and wetland fish and wildlife habitats in the San Joaquin Valley is currently inadequate. Further research is warranted.

Disadvantages associated with this option relate primarily to the above-discussed toxicity risks. Potential advantages include the ability to gain additional beneficial uses at relatively low costs from waters now managed as wastes.

Reallocation of freshwater supplies (F-12). See option G-16.

Altered sequence of water delivery (F-13). A conceptually simple approach to satisfying many fish and wildlife water needs in the San Joaquin Valley would involve altering the sequence in which water is currently made available to beneficial uses. At present, the majority of the water consumptively used in the valley is seasonally stored in large reservoirs and delivered to users via canals and a few reaches of natural river channels (principally in the Sacramento Valley), when such channels are conveniently situated to meet conveyance needs. In the San Joaquin Valley, major river reaches (e.g., the main stem San Joaquin River between Mendota Pool and Friant Dam) have been dewatered as a result of construction and operation of diversion dams and canals, primarily to provide water for agricultural uses on the east side and southern end of the valley.

At present, developed water is delivered directly to agricultural lands on the west side and southern end of the San Joaquin Valley. It then provides for a single beneficial use (i.e., irrigation) and, on an increasing acreage throughout the drainage problem source area, is then degraded to the point that it has few if any additional beneficial uses and is generally managed as a waste. If any usable supplies of water remain after agricultural uses, they are made available to help satisfy wetland and instream flow needs.

This option proposes to gain several additional beneficial uses from the public's water before it, and surface and subsurface receiving waters, are severely degraded through agricultural uses and drainage. Through this scheme, additional beneficial uses would be acquired merely by changing the manner through which water is currently delivered to agricultural lands, by serving instream and/or wetland uses enroute.

For example, those San Joaquin River waters stored behind Friant Dam that are currently destined for delivery to agricultural lands on the east side of the valley through the Friant-Kern and Madera Canals could instead be released below the dam into the natural river channel and serve water-quality, biological, recreational, aesthetic, and other instream, riparian, and neighboring wetland water needs enroute to the Delta. The water which reaches the Delta could be returned to the Tulare Basin farmlands through the California Aqueduct and, as needed, the Cross-Valley Canal.

A large variety of beneficial uses and needs could potentially be served through such a scheme, including: increased instream flows and fisheries; increased acreage of wetland and riparian habitats (and associated aquatic birds and other wildlife resources); decontaminated and restored habitats; improved instream water quality; increased pollution dilution; reduced treatment costs for downstream domestic, municipal, and industrial water users; improved riverine and Delta recreational opportunities; improved olfactory and visual aesthetics; and possibly increased economic benefits to local communities along the lower San Joaquin River and/or in the Delta should substantial increases in recreational use occur.

Disadvantages associated with this option include: an unquantified reduction (as a result of evapotranspiration losses and seepage) in the volume of water initially released below Friant Dam; reduced surface-water supplies

to the Friant-Kern and Madera Canals service areas; jeopardized repayment of project costs; possible impacts on the structural integrity of the Friant-Kern Canal should water deliveries be substantially reduced; increased Delta pumping and associated increased energy use, fishery impacts, and costs of irrigation water delivery to the Friant-Kern service area; possible increased ground-water pumping in the Friant-Kern service area and associated increased energy use and water costs; use of limited California Aqueduct pumping capacity; and possible social impacts to local communities in the Tulare Basin should irrigation water deliveries be substantially reduced.

Modifications to existing or proposed water storage projects and delivery systems (F-14). A number of existing and proposed water resources facilities (including dams/reservoirs and canals) could conceivably be either redesigned, structurally modified, or operated differently in order to increase the supply and/or quality of freshwater now available to San Joaquin Valley fish, wildlife, and their habitats. For example, proposed reservoirs could be redesigned and, as necessary, reauthorized (or the heights of existing dams could be raised) to provide additional reservoir storage volume that could be used to help satisfy the valley's fish and wildlife water needs.

Another example for helping meet fish and wildlife needs is changing reservoir operations to release water not needed for firm yield on a schedule which best meets fishery needs. This is being done on the Stanislaus River at the cost of some decrease in electrical power revenues, pursuant to an agreement between the USBR and CDFG. Another operating option for increasing streamflows for fish and wildlife is greater conjunctive use of reservoir and ground-water storage.

Existing and proposed water distribution systems could also be modified to alleviate problems associated with water distribution to wetlands and other

fish and wildlife habitats. For example, wildlife and water managers in the Grasslands area have developed plans and partially constructed a system (the Blake-Porter Bypass) designed to remedy (on an interim basis) quantity, quality, and scheduling problems related to delivery and distribution of water to wetlands in the area. This system (funding for which was contributed by State and local agencies) includes new water-control structures and new and enlarged canals and ditches. The new system allows separation of freshwater from drainage water, delivery of freshwater to most wetlands throughout the Grasslands, and conveyance of drainage water to Salt Slough and eventually the San Joaquin River. Similar projects (e.g., the Zahm-Sansoni-Nelson Plan and a recent proposal developed by local water districts) include the use of the San Luis Drain to convey freshwater and/or drainage water. Proponents believe that these projects would allow for even more widespread distribution of freshwater in the Grasslands area and would relocate (to a point further downstream on Mud Slough) the discharge of drainage water.

Advantages associated with this option include protection and possibly decontamination and restoration of habitats receiving the water. Disadvantages would vary by project and could include the costs and adverse environmental and other effects associated with construction, operation, and maintenance of any new or modified facilities.

Wetlands water storage (F-15). Wetlands in many areas of the valley could be managed to provide seasonal storage of freshwater in addition to the several other functions they already serve. If properly managed, such seasonal storage could benefit: fish and wildlife populations that rely on these areas to satisfy habitat needs (especially waterfowl and other aquatic birds); wetland owners and managers that need additional supplies of freshwater for optimum management; wetland decontamination and restoration

efforts; fisheries that are in need of substantial, additional instream flows; and other water users downstream from the wetlands that desire additional supplies. The water used to flood wetlands for the above-mentioned purposes could potentially originate from any of several sources (see discussion elsewhere in this subsection) and could be delivered through natural or constructed channels.

In the fall of 1987, the Grassland Water District (GWD) in cooperation with the USBR initiated a pilot field study of the feasibility, costs and benefits, water-quantity and water-quality effects, and other considerations associated with offstream water storage in GWD wetlands. Approximately 25,000 acre-ft of water was used to flood approximately 16,000 acres of wetlands in the northern portion of the district.

A similar experiment was initiated in the fall of 1988 by GWD in cooperation with CDFG and Ducks Unlimited. That project also involved flooding of approximately 16,000 acres of GWD wetlands with approximately 25,000 acre-ft of freshwater (USBR and CDFG, 1988). The water was obtained through purchase of storage from New Melones Reservoir, conveyed to the Delta through natural channels, and pumped from the Delta and delivered through the Delta-Mendota Canal.

Seasonal wetlands water storage has the potential to provide significant fish and wildlife benefits if the depth of flooding and scheduling of application and discharge of water coincide with the biological needs of wetlands-wildlife and instream-fishery resources.

The quantity and quality of water discharged from wetlands are changed as a result of use for management of wildlife habitat. As a result of evapotranspiration and seepage, 50 to 75 percent of the water applied to wetlands would not be discharged. According to preliminary data from the

1987-88 GWD/USBR program in the Grasslands area, surface discharge from the wetlands in mid-March 1988 was approximately 24 percent of the applied water. An unknown quantity of water is believed to have seeped underground, and an unknown percentage of that ground water would be expected to contribute to surface flows in the San Joaquin River.

Wetlands water use would also be expected to alter the quality of discharge waters by: increasing salinity (through evapotranspiration and evaporative concentration) and decreasing the load and perhaps concentrations of nutrients and many trace elements (through biological uptake-bioaccumulation). Use of higher-quality (lower salinity) water for wetlands flooding (e.g., use of Sierra Nevada runoff as opposed to pumped water from the Delta) would be expected to result in discharge water of proportionately lower salinity.

Improvement of Fish and Wildlife Resources

Agroforestry (F-16). See option D-1.

Management, development, reclamation, and acquisition of fish and wildlife habitats and associated public-use facilities (F-17). Irrespective of actions undertaken to specifically address drainage-related problems of the San Joaquin Valley, a broad variety of other actions could also be taken that would improve the status of the valley's fish and wildlife resources. Drainage-related contamination poses special threats to the valley's fish and wildlife populations because of the stresses those populations already suffer as a result of the significant, historic losses of habitat. In addition, fish and wildlife-related public values and uses have been adversely affected as a result of increased public health risks associated with the consumption of wild plants, fish, and wildlife from drainage-contaminated areas of the valley. Actions that could be taken to improve the valley's fish and wildlife

resources generally fall within two categories: (1) Preservation of remaining fish and wildlife resources, and (2) reclamation of lost habitats.

Protection of existing fish and wildlife habitats, populations, and associated public values and uses would not initially "improve" the valley's fish and wildlife resources. However, such actions would perform another vital function; i.e., stemming further losses and thereby providing a stable, biological foundation for improvement actions (i.e., actions that would increase the quantity and/or quality, including diversity and health, of fish and wildlife resources).

Protection of remaining fish and wildlife habitats could be accomplished through any of a variety of conventional means, including, for example: tax or other financial incentives (e.g., through provision of tax deductions for preserving native habitats); land-use regulatory controls (e.g., through land-use planning and/or zoning); and acquisition of privately owned properties which are potentially threatened with conversion to agricultural or other uses. Depending upon biological needs, local opportunities, degree and nature of threats, available funding, local, State, and national legal and political considerations, and/or other concerns, acquisition programs could assume any of several forms (e.g., from purchase of conservation easements from willing sellers, to negotiated, fee-simple purchase, to condemnation).

Additional fish and wildlife benefits could be provided through: purchase of existing agricultural or other lands and reclamation of lost habitats (e.g., through conversion of marginal farmlands back to grassland and/or wetland habitats); provision of adequate, firm freshwater supplies to such habitats; and development of public-access and use facilities.

Proposals to protect existing and develop new wetlands habitats in the San Joaquin Valley are central to a recently initiated cooperative effort by

Federal, State, and private parties concerned about diminishing wetlands habitats and associated waterfowl populations. The Central Valley Habitat Joint Venture (part of the North American Waterfowl Management Plan) proposes the following for the San Joaquin Valley: the protection of more than 35,000 acres of existing wetlands and the development of between 30,000 and 50,000 acres of new wetlands (through purchase of easements or fee simple acquisitions); the acquisition of adequate, firm freshwater supplies for Federal and State wildlife areas and some private duck clubs; and the improvement of wildlife habitats on agricultural lands (USFWS, 1987; USFWS and Canadian Wildlife Service, 1986). This effort is consistent with goals and/or policies of President Bush, the USEPA, USFWS, California Fish and Game Commission, and California State Senate, among others, of no net loss of wetlands (speech given by President George Bush to Ducks Unlimited--Sixth International Waterfowl Symposium, June 8, 1989, Crystal Gateway Marriott, Arlington, VA; USEPA, 1989; USFWS, 1985; California Fish and Game Commission, 1988; CA State Senate Concurrent Resolution 28, January 1, 1983).

The reclamation of fish and wildlife habitats in the valley would have benefits in addition to improvement of fish and wildlife values. For example, such new habitats could be sited and managed to offset losses associated with disruptive decontamination techniques (such lands would serve as mitigation as long as decontamination continued). Additionally, if wetland habitats were reclaimed (especially in the vicinity of evaporation ponds in the Tulare Basin), a wide variety of benefits would accrue to wildlife and the local agricultural community. Such benefits would include: provision of productive wetlands habitat (for migratory, wintering, and nesting uses) as partial replacement for the enormous historic losses of such habitat in the valley; provision of attraction habitat to lure birds away from toxic evaporation

ponds; and provision of alternative habitat for birds hazed away from toxic ponds.

Disadvantages associated with this group of options relate primarily to: costs associated with purchase, development, and management of new lands; and potentially some social impacts if such acquisitions caused dislocations of individuals.

Uncontaminated evaporation ponds-wetlands (F-18). Evaporation ponds constitute very attractive oases for wildlife (especially aquatic birds such as waterfowl and shorebirds). The ponds are attractive because of the scarcity of alternative wetland habitats in the valley (especially in the Tulare Basin) and because they are biologically very productive.

As a result of the discharge of untreated drainage water into evaporation ponds, and the natural processes of evaporative concentration, bioconcentration, and possibly biomagnification, aquatic plants and animals that make up the diet of aquatic birds have accumulated toxic concentrations of a number of trace elements in several valley ponds. Elevated frequencies of embryo deformities, deaths of apparently normal embryos, and complete nesting failures have been documented at a number of ponds (Ohlendorf, 1988; Schroeder et al., 1988; Skorupa, 1989; Skorupa and Ohlendorf, 1989; Skorupa and Ohlendorf, 1988). Thus, instead of benefitting wildlife, many San Joaquin Valley evaporation ponds now constitute extremely hazardous attractive nuisances.

In selected areas of the valley, the drainage waters, although in some cases quite saline, naturally contain very low concentrations of trace elements. If those waters (or other drainage waters which had been treated to remove trace elements) were disposed of in evaporation ponds, the ponds could be managed to increase their attractiveness to wildlife and thereby

potentially serve as alkaline wetlands of benefit to wildlife. Such ponds might require siting near rivers or streams and regular flushing with freshwater (e.g., during flood events) in order to ensure that evapoconcentration and/or bioconcentration did not result in the accumulation of toxic concentrations of trace elements in wildlife food-chain organisms.

A great deal remains unknown about not just the biology, biochemistry, and toxicology of evaporation ponds, but also their physical and chemical characteristics and hydrological and geochemical properties. Further study of biogeochemical processes affecting the bioavailability, bioaccumulation, and toxicity of very low concentrations of trace elements of concern over long periods of time are warranted before this option can be wholeheartedly endorsed.

INSTITUTIONAL CHANGES (G)

It must be recognized that although growers and public and private fish and wildlife managers are the actual managers of land and water, the activities they undertake occur under an umbrella of governmental laws, policies, and practices--local, regional, State, and Federal. Some changes in this institutional framework may help solve drainage problems. The options that follow are being analyzed for their general feasibility and the legal, economic, and environmental impacts. The results of those analyses will be published in subsequent reports.

<u>Increase price of water through water supply contracts (G-1)</u>. As the price of water increases, irrigators become more concerned with water conservation and the efficiency of irrigation practices. In the principal study area, water districts purchasing water do so from the USBR or DWR, and the price they pay is established in contracts. Water districts then pass

those costs to the irrigators. Implementing this option would require the water supply agencies to adopt a policy of increasing rates for the purpose of promoting water conservation and drainage reduction, and to negotiate revisions in existing service contracts.

To raise the price of water on the basis of water conservation policy rather than a cost-of-delivery basis would require a fundamental shift in Federal and State policies, and would probably require substantial revision of Federal and State laws. Preliminary analyses indicate that increases in water prices possible under existing Federal law would not be sufficient to cause significant changes in irrigation practices. Significantly higher prices, not yet determined, could lead growers to apply less water to reduce deep percolation, change crops grown, or reduce the number of acres in irrigation. Any changes in Federal or State water-pricing policy or law would affect not only irrigators in the study area, but all irrigators with Federal or State contracts, respectively, throughout the United States or California.

Water districts increase price of project water (G-2). In this option, water districts with drainage problems would take direct action by raising the price of water supplied by the CVP or SWP to growers in an effort to reduce drainage-water volume. Under existing California law, water districts are not permitted to earn a profit. If individual growers were charged more for water and the excess funds rebated or applied to drainage management programs by the district, this might be within existing legal limits. This option is being examined further.

Modify or eliminate irrigation subsidies (G-3). Under existing Federal Reclamation law, growers are not required to repay the full construction cost of the facilities required to supply irrigation water. A determination is made of the irrigators' "ability to pay," which establishes the maximum

repayment rate and must at least equal annual operating costs. Revenues from the sale of power generated at multipurpose Federal dams are also used to subsidize the difference between irrigators' ability to pay and the full repayment of construction costs. In addition, if irrigators meet the qualifications under Reclamation law, no interest is charged on the repayment of any portion of construction costs.

The SWP provides a subsidy to growers through State financing of water-control facilities.

The theoretical basis for this option is that, if water users paid the full costs of agricultural water, significant volumes of water would be conserved and the drainage problem would lessen.

Require farmers to pay only for water actually used (G-4). More flexibility is needed to enable individual growers and district managers to make decisions on irrigation water application leading to less production of drainage water. This option would allow water districts to pay only for water actually used rather than a fixed contractual amount, whether all the water is used or not. The water wholesaler would either keep unused water (in storage, as appropriate) and not charge the district for it or would give the district credit for water not used. Credits would allow districts to postpone delivery of water until the time it is needed. These changes would provide an incentive for increased water conservation and drainage reduction. This option could be implemented in conjunction with tiered water pricing and water transfers and marketing.

Use tiered water pricing at water district, CVP, or SWP levels (G-5). Currently, growers who purchase irrigation water from districts pay the same per-unit cost for all water under the same contract provisions. Tiered water pricing provides the first block of water at one unit price with subsequent

blocks priced successively higher. This would encourage water conservation by increasing the unit cost of water as total use increases. This was tried by Pacheco Water District during 1988 with success in reducing water use and is being tried by Broadview Water District and Pacheco in 1989.

CVP and SWP contracts with individual water districts do not currently contain provisions for increasing per-unit repayment rates as water use rises. Tiered water pricing at the Federal and State levels would require changes in policy and/or law.

Modify water-transfer and water-marketing policy (G-6). Water trading is currently practiced within individual Federal and State irrigation service areas. Current practice restricts the price of Federal water traded to the price level in the water contract (i.e., no profit can be made by the seller). Transfer of SWP water outside of the boundaries of the contracting water entity requires approval of DWR. Water transfers are usually conducted on an annual, nonfirm basis. More liberal transfer policies by State and Federal governments could lead to increased trading and an increased value placed on transferred water, which, in turn, could encourage water conservation.

Conceptually, water marketing involves selling water at a price reflecting its free market value. There are opportunities for entities with an allocated firm water supply to sell all or a portion of the supply to other users, including other agricultural users, municipal and industrial users, and managers of fish and wildlife resources. Permitting irrigators to sell water in an open market could be an incentive for water conservation. Growers with severe drainage problems (in terms of concentration of undesirable constituents or potential high cost of drainage management) might find it attractive to withdraw selected lands from irrigation and sell some or all of the water to others. This could simultaneously ameliorate drainage and

drainage-related problems and the adverse economic impacts of their resolution on growers.

Rebate taxes based on total water management efficiency (G-7). This option would provide growers with a tax rebate based on their success in reducing the amount of applied irrigation water, to the extent that such water affects the overall production of drainage water.

Alter tax structures and rates (G-8). This option would encourage water conservation by modifying income-tax schedules to provide credit for investments in water conservation facilities--facilities that would lead to a reduction in drainage-water volume produced from irrigated agriculture.

Authorize use of CVP and SWP water for dilution of agricultural drainage (G-9). This option would require modification of existing laws and policies to allow the use of CVP and SWP water for dilution of agricultural drainage prior to its discharge to a receiving-water body such as the San Joaquin River. For example, one change would require the SWRCB to acknowledge dilution as a reasonable use of water. In most instances, the diluted agricultural drainage would become available for reuse. This option may be an interim means of disposing of drainage water--recognizing, however, that instream water-quality objectives of the State would have to be met.

Impose drainage-effluent fee (G-10). A drainage-effluent fee could be imposed on growers and/or water districts that produce and discharge drainage from the farm or district. The fee would likely be set at a fixed per-unit value (e.g., $/acre-ft of drainage or $/unit of drainage water quality) so that the total amount collected from a farmer or district would increase in proportion to: (1) An increase in the quantity of drainage produced, or (2) a deterioration in drainage-water quality based on the quantity and/or quality of drainage generated on-farm or within a water district. Proceeds from the

fee collection could be used to offset costs of drainage management incurred by a drainage district or regional government. The fee would be expected to encourage growers and districts to improve water conservation and drainage management practices.

Limit drainage effluent (G-11). This option would limit the amount of drainage discharged from individual farms, districts, or regions. It could be imposed by the CVRWQCB through the wasteload allocation process designed to meet water-quality objectives and would be applied in those drainage areas with extremely poor-quality drainage effluent (e.g., those with a high concentration of selenium). It would be necessary for drainage management organizations to limit drainage production or develop local disposal options if the drainage limit were exceeded. This option would provide an incentive to minimize drainage production and drainage management costs. Penalties for exceeding the discharge limits could include fines or curtailment of surface irrigation water deliveries.

Trade drainage-effluent discharge permits (G-12). Assuming a drainage permit system was established, this option would allow growers to trade permits to discharge specified loads of constituents, such as selenium, boron, and salts, in drainage effluent. The permits would apply to off-farm discharge, including discharge to surface-water bodies and regional evaporation ponds. A quasi-market could be created to maximize flexibility of decisionmaking at the farm level and minimize administration by State and local water-quality regulatory agencies and water/drainage districts.

Form a regional drainage district (G-13). Drainage and drainage-related problems do not coincide with boundaries of existing water districts and other water entities. The attainment of drainage management goals may require coordinated regional efforts to achieve effective and equitable solutions.

Solutions to drainage and drainage-related problems may best be approached on a regional basis, including the formation of one or more regional drainage districts. Boundaries would most likely be determined by local water districts, and drainage districts could be formed within existing water districts or by combining districts on a regional basis. The CVRWQCB reported the desirability for regional drainage districts in its draft San Joaquin Basin Plan Amendment (CVRWQCB, 1988b).

A regional drainage entity could assist members (whether individual districts or growers) in developing and implementing acceptable drainage solutions, coordinating and assisting irrigators in complying with the requirements of discharge permits, and formally identifying and assigning drainage-related responsibilities and costs. A regional drainage entity could help simplify relationships between member districts and growers and regulatory agencies. A regional approach would permit a more comprehensive set of drainage management actions than those likely to be employed by individual growers or districts, and could result in more economical solutions because of its size and economies of scale.

State legislation allows formation of a drainage district through a simple majority vote. District formation may require incentives to join, as well as disincentives for not joining. Incentives might include State aid in financing, while penalties might take the form of regulatory pressure from the CVRWQCB. Districts would need to have the power to collect fees from member districts or growers and issue bonds for the purpose of financing construction of drainage management and disposal facilities.

<u>Allocate CVP and SWP water to wetlands with increased subsidy (G-14)</u>. This option would provide relatively inexpensive water supplies to private and public wetlands to improve the quality of wildlife habitat. As noted in the

description of option G-3, irrigation water supplied by both the CVP and SWP involves subsidy elements, with those of the CVP generally being the greater of the two. Under this option, additional CVP and SWP water would be allocated for wetland management in the San Joaquin Valley with a subsidy element which would exceed that currently provided to irrigation supplies. Additional water for valley wetlands would increase protection of wildlife, could be used for decontamination and restoration, and in some areas, discharge flows could benefit fisheries.

Authorize CVP & SWP water for environmental and other uses before agriculture (G-15). This option would be required to implement option G-16 and similar suggestions that water be utilized for environmental and other uses prior to its use for irrigated agriculture. Some water contracts specify water-quality limits for delivered water and, if implemented, this option might result in those limits being exceeded. Therefore, some modifications in those contracts might be required. Additional facilities for delivery of water discharged from wetlands to agricultural lands may be required. Cooperative agreements may be necessary to create the opportunity to use existing facilities and/or the authority to construct additional facilities to provide the required water delivery capability.

Reallocate water from agriculture to fish and wildlife uses (G-16). This option involves the reallocation of surface water from agricultural uses to the support of fish and wildlife through increased instream flows and/or additional supplies for wetland habitats. It could be accomplished through the implementation of any of several mechanisms. One is improving water conservation measures in drainage problem areas, and another is retiring selected agricultural lands from irrigated agriculture. Both would result in a reduced demand for irrigation water imported by the CVP and SWP. This water

could be reallocated for fish and wildlife uses in the valley. This option could require a formal reallocation of contract supplies from agriculture to fish and wildlife purposes. Several agreements among State and Federal agencies and local water districts might be required to effect this option.

A third method involves the California constitutional requirement that water be put to beneficial use and the prohibition against waste or unreasonable use of water. Many areas in the valley now require, or in the future are expected to require, installation of on-farm drains in order to maintain agricultural productivity. Much of the drainage water has high concentrations of salt and trace elements. A number of treatment processes are capable of removing salts and trace elements from drainage water, but they are expensive and may not be affordable for affected farmers. It could be construed in the absence of safe, affordable treatment and disposal that the application of water to lands high in salts and trace elements constitutes an unreasonable use of water. Further, it could be determined that application of irrigation water in excess of evapotranspiration and minimal leaching requirements constitutes a waste of water. Theoretically, either of these could provide the legal basis for reallocating water from agriculture to fish and wildlife. (See option F-3.)

There are many complex and unanswered questions concerning this option such as compensation for water rights and contract repayment obligations. These questions are being addressed in analyses currently being conducted by the SJVDP.

<u>Reauthorize CVP and SWP to include fish and wildlife with equal consideration to other purposes when allocating water resources (G-17)</u>. This option includes a change in water project authorizations to emphasize equal consideration for allocating water supplies to fish and wildlife and related

purposes. This would increase and/or improve habitat and would probably reduce irrigation supplies and agricultural drainage. This option would probably require federal and state legislation.

CHAPTER 4. PRELIMINARY ALTERNATIVES

Development of the best in-valley solutions to drainage and related problems in the study area requires the formulation, evaluation, and comparison of a wide range of alternative plans. This is currently the major effort of the SJVDP. Some 70 options that potentially could contribute to management of the problems have been identified and are described in Chapter 3, including information on their major advantages and disadvantages. This chapter presents a description and evaluation of preliminary alternatives formulated for individual planning subareas. A broader range of alternatives will be presented in a final report in 1990.

There is no single solution to the drainage and related problems of the valley and no single option that will solve all or even a major part of those problems. The challenge is to find combinations of options (alternatives) that will provide the best short- and long-term solutions in each planning subarea. The planning period is 1990 to 2040 with an interim planning horizon of 2000.

Alternatives will be compared with each other and with expected "future-without" conditions to determine trade-offs between plans and to assess the change expected from "future-without" conditions. Evaluation criteria described in the Drainage Program's "Technical Report on Formulating and Evaluating Drainage Management Plans" (1988b) will be used in making the comparisons.

Final plans will be developed on the basis of information obtained from the evaluation of alternatives and from public comments. Two preliminary alternatives are presented here for the interim planning horizon, year

2000: (1) The "future-without" alternative, which represents conditions likely to occur in the absence of coordinated comprehensive action to solve valley drainage problems, and (2) the "available technologies" alternative, which is based on available, proven irrigation and drainage technologies.

THE "FUTURE-WITHOUT" ALTERNATIVE

The "future-without" alternative represents conditions expected to exist in the valley if coordinated, comprehensive actions are not taken by government and the private sector to solve the drainage problems. The President's Council on Environmental Quality requires that all Federal planning studies include a future-without alternative as part of project planning. (See 40 CFR 1500.) The future-without alternative is intended to give planners and interested and affected publics a common ground from which to judge the need for actions to change existing trends. It also provides a baseline against which the economic, environmental, social, institutional, and physical effects of planned actions may be measured to determine their positive or negative values.

Development of the future-without alternative involves: (1) Describing a general, overall theme of the future in the valley, (2) developing a set of assumptions about economic, environmental, social, institutional, and physical conditions in the valley and projecting trends, and (3) quantifying the results of these assumptions specific to the planning subareas. The general, overall theme and assumptions about future conditions in the valley are summarized here. A detailed evaluation of future-without conditions will be presented in the Program's final report in 1990.

In February and March 1987, the SJVDP conducted multidisciplinary workshops designed to develop likely scenarios of the future in the absence of

a coordinated, comprehensive plan to solve the valley's drainage and drainage-related problems. Participants included valley farmers, wildlife refuge managers, water district managers, academicians and researchers, and Federal and State agency personnel. The groups discussed major themes and trends forcing changes in agricultural drainage-related conditions in the valley. It was concluded that central themes shaping future trends were related primarily to the public's desire to protect fish and wildlife and to sustain agriculture in the valley.

Assumptions regarding economic, environmental, social, institutional, and physical conditions and trends in the valley are summarized below. A general overriding assumption was that catastrophic natural events would not occur and there would be no major changes in the national, political, economic, or social climate.

More specific assumptions and trends are:

- The present trend toward less Federal government and more privatization will continue. Government expenditures for major water projects will continue to decline, and Federal farm subsidies will be reduced gradually. More responsibility for natural resources management will be forced on State and local governments and the public sector.
- Public pressure for environmental protection will increase. Environmental regulations will become more stringent, and governmental enforcement of those regulations will increase. This could result in user charges, taxes, and penalties to aid environmental protection.
- Agricultural economic conditions will remain relatively stable. The United States, California, and the San Joaquin Valley will compete

favorably in world agricultural markets. Irrigated agriculture in the valley will be able to afford and install some drainage improvements but will not be able to do so uniformly, and some land will go out of production as a result of drainage and related problems.

- California's population will continue to grow, resulting in increased urbanization of the San Joaquin Valley including west-side agricultural lands, which will be increasingly converted to urban, residential, commercial, and industrial uses (with their attendant transportation and communication needs). Air pollution, waste generation, and noise will increase.
- Imported water supplies to the study area will not be increased.
- There will be a shift in the northern part of the valley from agricultural water use to urban uses.
- Existing valley wetlands and wildlife areas will be preserved and protected, but no new areas or water supplies will be developed.
- Overall, surface- and ground-water quality in the valley will continue to deteriorate.
- The land area affected by a high ground-water table will increase, the shallow ground water will become more saline, and agricultural land will go out of production as a result.
- Except for use of the San Joaquin River, no drainage outlet from the valley will be provided.
- Independent and uncoordinated actions related to agricultural drainage will result in litigation, not only between agriculture and environmental interests but among similar interest groups.

- Piecemeal legislation and institutional change will add to the drainage problem, resulting in a narrowing of the range of choices for water, land, and fish and wildlife managers and significant diseconomies to most concerned parties.

THE "AVAILABLE TECHNOLOGIES" ALTERNATIVE

This alternative is formulated from options of irrigation and drainage technologies currently available and proven effective in the reduction or management of drainage water, or assumed to be available technologically and to show promise of being cost-effective by the year 2000. The selected options were applied to: (1) Irrigated land that is projected to overlie "problem water" in the year 2000, (2) fish and wildlife habitats that have been and are likely to be adversely affected by agricultural drainage, and (3) valley sites that pose selenium-related public health risks. Options were selected and configured for the particular conditions in the individual planning subareas.

The alternative addresses planning objectives for: (1) Agriculture, (2) fish and wildlife, (3) public health, and (4) water quality. The objective for agriculture is to reduce or manage the annual volume of problem water by the year 2000. Objectives for fish and wildlife are to protect existing resources, restore drainage-contaminated habitats, and provide fish and wildlife with a reliable firm water supply to substitute for contaminated subsurface drainage waters, where such waters have been used by fish and wildlife. The alternative must also provide for the protection of public health and meet State water-quality objectives.

Shallow Ground-Water Quality Zones

There is a considerable range of variability in the quality of shallow ground water on the west side of the valley and in the uses that can be made of that water. To facilitate analyses and planning for drainage-water management, the shallow ground-water area of each planning subarea was divided into water-quality zones. A total of 16 zones have been delineated in the study area. The zones are defined in terms of concentrations of major substances of concern (i.e., salinity, boron, selenium, molybdenum, and arsenic) dissolved in shallow ground water. The delineation of zones allows selection of options that are best suited to management of the particular-quality drainage water of each zone. (The locations and chemical characteristics of each of the shallow ground-water quality zones are shown later in this chapter in the sections on planning subareas.)

Annual Problem-Water Volume

Estimates were made of the annual volume of problem water that must be reduced or managed to sustain agriculture and to avoid or mitigate drainage-related problems in the study area by the year 2000. Estimates were made for each zone in each subarea except Northern. (The Northern Subarea has no immediate drainage problem but is affected by drainage problems in the Grasslands Subarea through drainage-water discharges to the San Joaquin River.) The estimates of problem water were developed using currently available information and analyses, including work accomplished by the IDP in the late 1970's, USBR work in the early 1980's, DWR data from the mid-1980's, and USGS information and interpretations made during 1986-89.

The estimates of problem water reflect projections of the irrigated land area expected to be drained by the year 2000, including lands currently being drained. This "drained area" comprises lands adversely affected by:

(1) Shallow ground-water levels 0-5 feet below the land surface, (2) salt concentrations (as EC) above 5,000 us/cm (3,200 ppm TDS) in the shallow ground water, and (3) boron concentrations above 8 ppm in the shallow ground water. The drainage-water volume produced from affected lands averages 0.7 to 0.8 acre-foot per acre. (Estimates of drained area and problem-water volumes for the individual zones are included in the subarea descriptions later in this chapter.)

Planning Methodology

Agricultural component. A common methodology was used to develop the agricultural component of the available technologies alternative for each of the shallow ground-water quality zones. The methodology involves seven steps to manage the volume of problem water in a given zone, as described below. Table 4-1 is a summary illustration of the planning methodology using Zone A of the Grasslands Subarea in a step-by-step example.

Zone A of the Grasslands Subarea was selected for illustration because more options are utilized for it than for any of the other water-quality zones in the study area. The alternative involves: (1) On-farm water conservation and drainage management, (2) discharge to the San Joaquin River, (3) propagation of eucalyptus trees and saltbush (reusing drainage water and managing the deep percolation from the reuse), (4) disposal of drainage water in evaporation ponds made bird-safe or bird-free, and (5) a minor amount of storage of drainage water in the semiconfined ground-water aquifer. Several of the steps and actions (options) utilized are depicted in Figure 4-1, which illustrates a combination of several drainage-water reuse and disposal options.

Step 1 (Estimate volume of problem water)--The first step involves estimating the amount of irrigated land having a water table within 5 feet of

Table 4-1

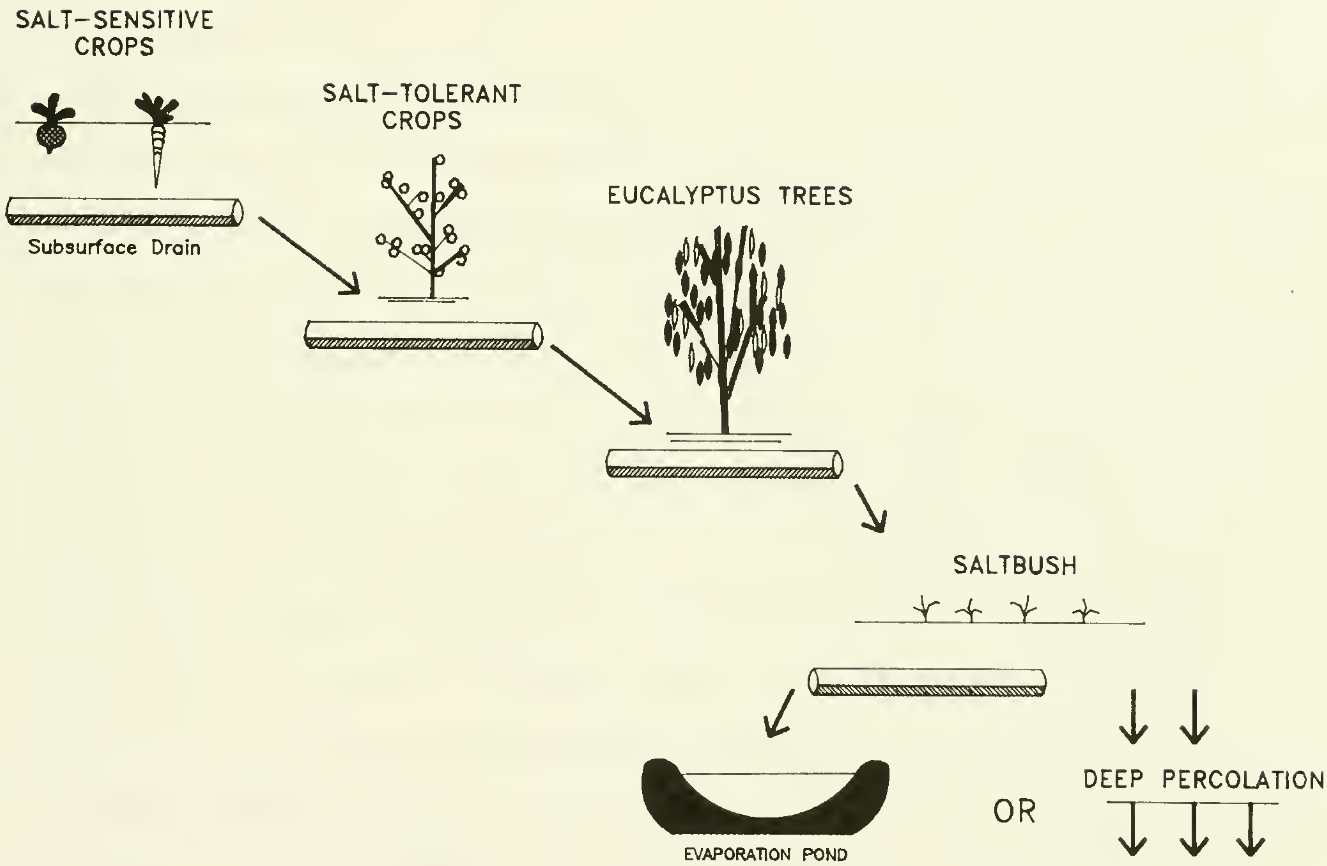
SUMMARY ILLUSTRATION OF PLANNING METHODOLOGY
FOR AGRICULTURAL COMPONENT OF
AVAILABLE TECHNOLOGIES ALTERNATIVE
(Zone A, Grasslands Subarea)

Step	Action	Result (acre-ft of water)
1	Estimate volume of problem water.	53,000
2	Reduce volume by on-farm water conservation and drainage management (14,000 + 7,000 + 3,400).	-24,400
	Remaining problem:	28,600
3	Discharge to San Joaquin River (volume that can be assimilated and meet State water-quality objectives).	- 9,000
	Remaining problem:	19,600
4	Grow 2,600 acres of eucalyptus trees, which consume 13,000 acre-ft and "save" 1,900 acre-ft additional.*	-14,900
	Remaining problem:	4,700
5	Grow 1,000 acres of saltbush to consume 2,500 acre-ft and "save" 600 acre-ft.*	- 3,100
	Remaining problem:	1,600
6	Use disposal capacity of existing evaporation ponds (50 acres).	- 200
	Remaining problem:	1,400
7	Pump the ground water underlying the saltbush to store 1,400 acre-ft.	- 1,400
	Remaining problem:	0

* This is an estimate of the water that no longer will become deep percolation because of the land-use change that occurs when eucalyptus trees, saltbush, and evaporation ponds replace irrigated crops. It is assumed that subsurface drainage associated with these new land uses will be controlled or obviated.

FIGURE 4-1

Illustration of a Combination of Reuse and Disposal Options



the land surface that is currently drained or is expected to be drained by the year 2000. It is estimated that 72,000 acres in Zone A of the Grasslands Subarea would be drained in the year 2000, yielding a problem-water volume of approximately 53,000 acre-feet (72,000 acres X 0.74 acre-ft/acre).

Problem-water quality in Zone A is characterized generally as moderate-to-high salts (TDS), high boron, and very high selenium. The salt levels would not severely limit drainage-water reuse. High boron levels would limit some reuse options, while high selenium levels would limit the amount of drainage water that could be discharged to receiving environments (e.g., wildlife areas, the San Joaquin River, and evaporation ponds).

Step 2 (Irrigation and drainage management)--It was assumed that about half of the growers would modify existing or adopt new technologies to reduce irrigation water application, thereby reducing deep percolation. Using information on water quality, soils, and irrigation facilities and practices in Zone A, it was estimated that between the years 1990 and 2000 the furrow lengths in irrigation systems on about 50 percent of the drained lands, or 35,000 acres, would be reduced from 1/2 mile to 1/4 mile. Excess applied water would be captured at the end of the 1/4-mile furrow for irrigation reuse. The reduction in problem-water volume was calculated to be 14,000 acre-feet annually. In addition, it was assumed that deep percolation would be reduced by 7,000 acre-feet annually through improvements generally in irrigation water management. These improvements would be made possible, in part, through increased development and use of information on crop water needs.

It was also estimated that shallow ground-water levels would be controlled by drainage system management on about 25 percent of the problem water lands, or about 17,000 acres. This would increase the amount of

subsurface water used by crops as evapotranspiration, thus decreasing the amount of applied irrigation water and resultant deep percolation. The reduction in problem water would be 3,400 acre-feet annually.

A total of 24,400 acre-feet, or 46 percent of the problem water, could be managed through on-farm water conservation and drainage management.

Step 3 (Discharge to stream systems)--It is estimated that 9,000 acre-feet of problem water could be disposed of by discharge to the San Joaquin River, primarily through Mud and Salt Sloughs. This volume would contain a selenium load that could be assimilated by the river without exceeding the proposed State water-quality objective of 5 ppb. This volume is about 25 percent of the drainage-water volume and selenium load discharged from Zone A in 1988.

Steps 4 and 5 (Reuse)--To help manage the remaining problem water, 15,500 acre-feet of drainage water collected from 35,000 acres of land would be used to irrigate 2,600 acres of eucalyptus trees. These trees would consume water at the rate of 5 acre-feet/acre/year, thereby disposing of 13,000 acre-feet/year (plus "saving" 1,900 acre-feet of deep percolation that would have occurred from a normal crop).

To maintain vigorous growth, the eucalyptus trees must be drained (about 1.5 acre-feet/acre/year), with the resultant drainage water used to grow 1,000 acres of saltbush (Step 5), which is even more salt tolerant than eucalyptus. Saltbush would consume water at the rate of 2.5 acre-feet/acre/year, thereby disposing of 2,500 acre-feet/year (plus "saving" 600 acre-feet of deep percolation that would have occurred from a normal crop). At this point, the process of reducing the residual problem-water volume would result in drainage water so salty and high in boron that it could not be used in plant growth. It would have to be treated, processed for

mineral recovery, used in solar ponds for power generation, and/or stored. Because the first three options are not expected to be available by the year 2000, storage is the option used for the remaining problem water.

Steps 6 and 7 (Storage)-- Steps 6 and 7 involve storage and disposal of drainage water in existing evaporation ponds and in the shallow ground water underlying the saltbush. In Zone A, there currently is one 50-acre pond that could store and dispose of 200 acre-feet/year. The remaining 1,400 acre-feet/year would be managed by pumping approximately the same volume of deep ground water of adequate quality for use as a fish and wildlife supply or for blending with the irrigation supply. Pumping would lower the water table, thus freeing up space for storage of deep percolation below the root zone of the saltbush.

Fish and wildlife resources component. For planning purposes, the estimated reductions in drainage water--plus any newly developed water of adequate quality (e.g., pumped ground water)--that could result from the available technologies alternative are considered to be future water supplies for fish and wildlife. For the study area as a whole, these additional water supplies (which total about 200,000 acre-feet) were allocated in the following priority: (1) To substitute for drainage water used on wildlife areas in the past, (2) to attract upstream migrating salmon into the Merced River, and (3) to firm up water supplies for existing public and private wetlands. Substitute water supplies to wetlands in the Grasslands area would also facilitate decontamination and restoration of those habitats, and would be released into the San Joaquin River to improve conditions for downstream migration of young salmon. Firming up wetland water supplies in the Tulare

Basin would provide additional protection to aquatic birds currently using toxic evaporation ponds in that area. Specific plans for use of water for fish and wildlife are described for individual subareas later in this chapter.

Public health component. Actions needed to protect public health are included in the available technologies alternative for each subarea. Both State and Federal agencies have issued health advisories and local officials have posted warning signs regarding consumption of fish and wildlife from certain areas known to be contaminated with selenium in the western San Joaquin Valley. Public health risk assessments being conducted for the SJVDP for specific trace elements are not yet completed; therefore, detailed protective measures have not been identified for all substances of concern for all subareas. In the interim, however, certain actions can be taken to reduce potential public health risks, including: (1) Continuing to publish public health warnings in fishing and waterfowl hunting regulations for affected areas, (2) posting warning signs at public access points along contaminated waterways and evaporation ponds, (3) constructing fences around contaminated evaporation ponds, (4) continuing to monitor wild foods collected in the four southern subareas, and (5) providing public information and education programs before and during the waterfowl hunting season.

PLANNING SUBAREAS

The five planning subareas are addressed in separate sections in this chapter. Each subarea is discussed in terms of: (1) Agriculture, (2) public health, and (3) fish and wildlife resources. The first part of each section includes descriptive information, a summary of drainage and related problems specific to the subarea, and planning objectives. The second part of each

subarea section comprises the available technologies alternative, tailored to individual water-quality zones. The Northern Subarea is presented first, followed by the Grasslands, Westlands, Tulare, and Kern Subareas.

NORTHERN SUBAREA

The Northern Subarea (Figure 4-N1) comprises about 369 square miles (236,000 acres) of predominantly rural land in western San Joaquin and Stanislaus Counties. The subarea is about 50 miles long and 7 miles wide and extends from about Tracy in the north to Newman in the south. The eastern boundary of the subarea follows generally the San Joaquin River; the western boundary lies along the base of the Coast Range foothills. The major land use is irrigated agriculture.

The estimated 1989 population of the subarea is 37,500. Several small towns in the subarea are growing rapidly (over 5 percent a year) due to urban overflow from the San Francisco-Oakland metropolitan area. The lands with present or potential drainage problems are located near the San Joaquin River, and represent a minor part of the irrigated lands in the subarea.

Irrigated Agriculture

Water supply. Irrigation water supplies in the Northern Subarea consist of diversions from the Delta, diversions from the San Joaquin River, and local ground water. The major water conveyance facility is the Delta-Mendota Canal, which was completed to the subarea in 1951. The annual firm irrigation water supply is about 510,000 acre-feet: 315,000 acre-feet from the DMC, 165,000 acre-feet from the San Joaquin River, and 30,000 acre-feet from ground water. There are 14 water districts and 2 drainage districts in the subarea.

Drainage-related water quality. Figure 4-N2 shows shallow ground water at depths of 0-5, 5-10, and 10-20 feet below the land surface in 1987. The present (1987) quality of the shallow ground water is indicated by the concentrations of salts (as electrical conductivity), boron, selenium, molybdenum, and arsenic, which are shown in Figures 4-N3, 4-N4, 4-N5, 4-N6, and 4-N7, respectively. Unlike other subareas, selenium concentrations in the shallow ground water in the Northern Subarea seldom exceed 5 ppb. Concentrations of boron and salts are slightly elevated in some locations. The quantity and quality of waters discharged or seeping into the San Joaquin River from this subarea are shown in Table 4-2.

Table 4-2

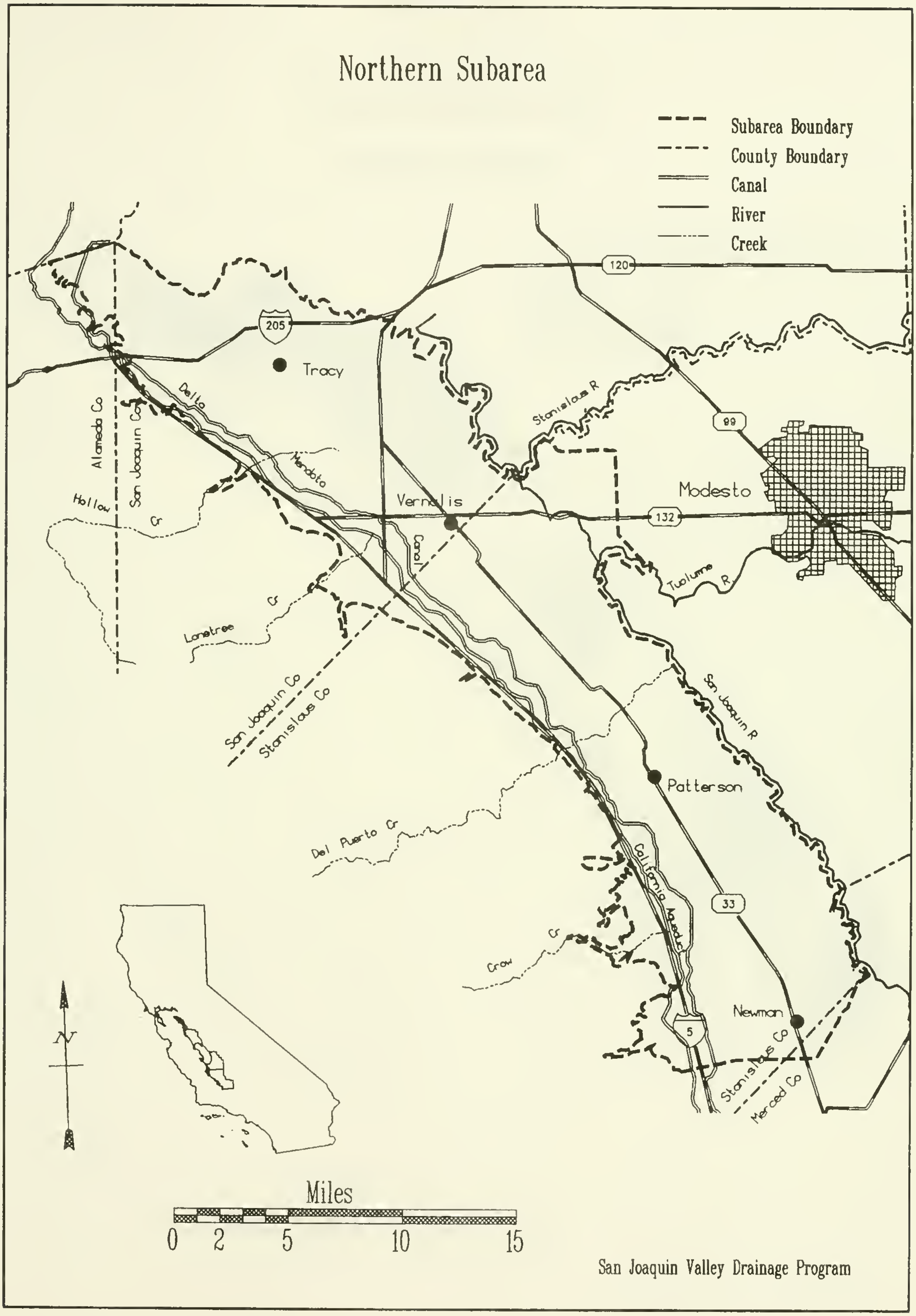
QUANTITY AND QUALITY OF DISCHARGE TO THE SAN JOAQUIN RIVER - NORTHERN SUBAREA
(Mean Concentrations of Dissolved Constituents)

	Volume (acre-feet)	TDS (ppm)	Boron (ppm)	Selenium (ppb)
Surface Drainage	62,000	400	0.2	<1.0
Subsurface Drainage	18,000	1,900	1.8	2.9
Ground-Water Seepage	119,000	900-2,700	Not available	Not available

Source: SJVDP, based on data from SWRCB, CH2M Hill, and USBR.

Because irrigation diversions from the San Joaquin River occur primarily during low-flow periods when salinity concentrations are elevated, crop diversity and production in the subarea are adversely affected. The quality of San Joaquin River water generally improves as the river flows north from its confluence with Mud Slough because the contribution of good-quality water from east-side tributaries such as the Merced River reduces the concentration

FIGURE 4-N1



Northern Subarea
Subarea Boundary
County Boundary
Canal
River
Creek
120
205
Tracy
99
Modesto
Stanislaus R
Delta
Mendota
Vernalis
132
Canal
Tuolumne R
Alameda Co
San Joaquin Co
Hollow Cr
Lonetree Cr
San Joaquin Co
Stanislaus Co
San Joaquin R
Patterson
Del Puerto Cr
California Aqueduct
33
Crow Cr
Newman
5
Stanislaus Co
Merced Co
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-N2

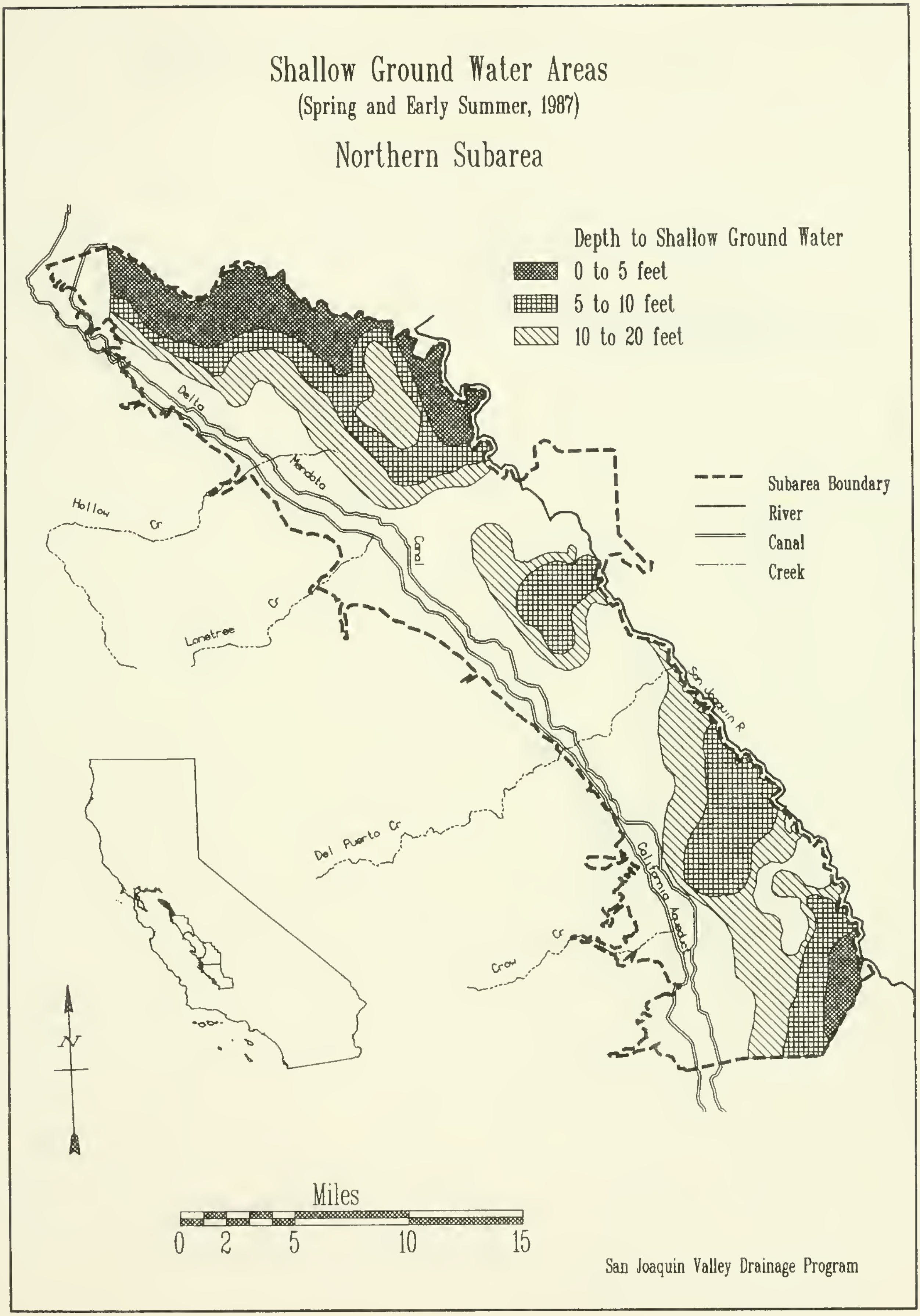

Shallow Ground Water Areas
(Spring and Early Summer, 1987)
Northern Subarea
Depth to Shallow Ground Water
0 to 5 feet
5 to 10 feet
10 to 20 feet
Subarea Boundary
River
Canal
Creek
Delta
Mendota
Canal
Hollow Cr
Lonetree Cr
San Joaquin R
Del Puerto Cr
California Aqueduct
Crow Cr
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-N3

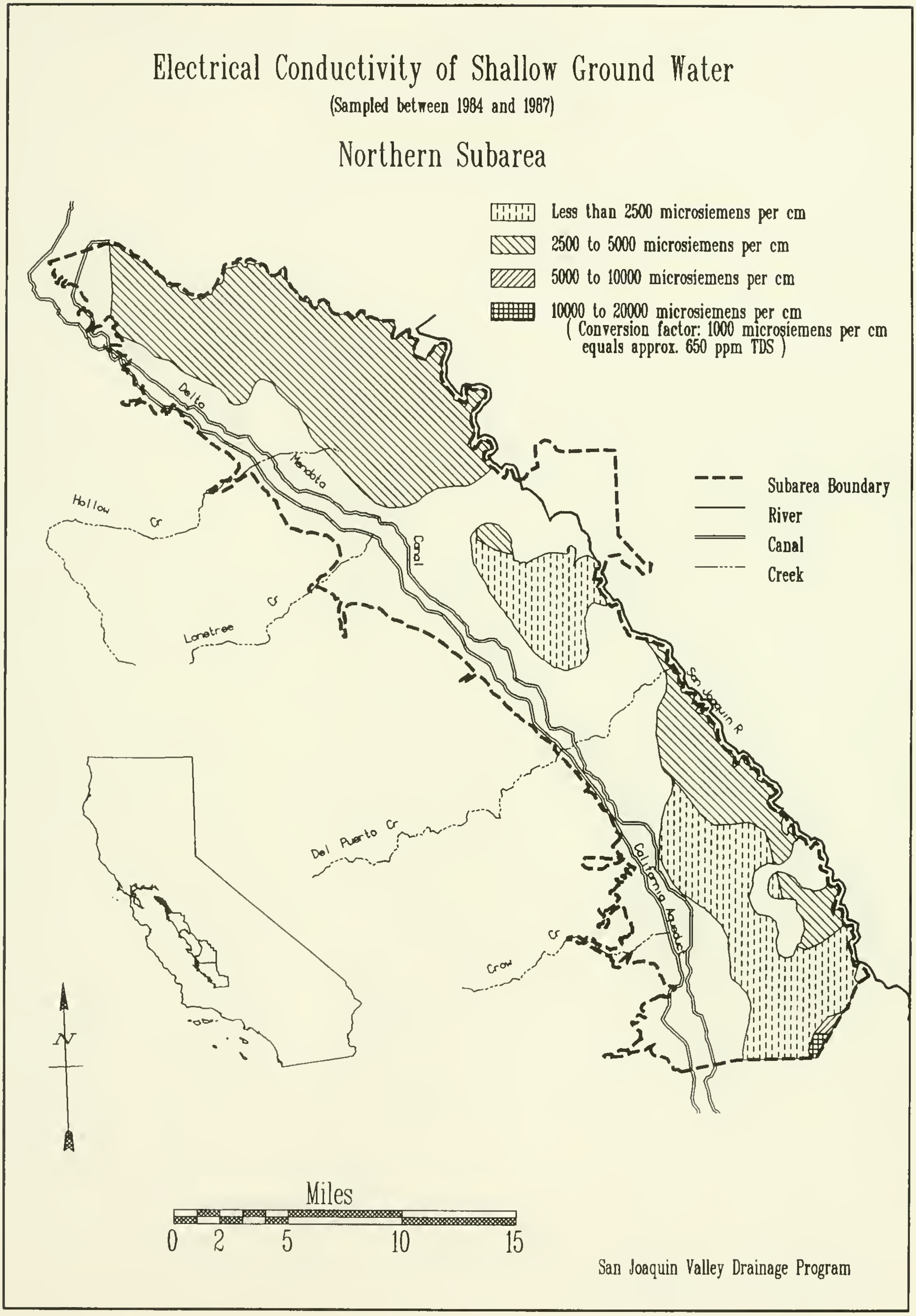
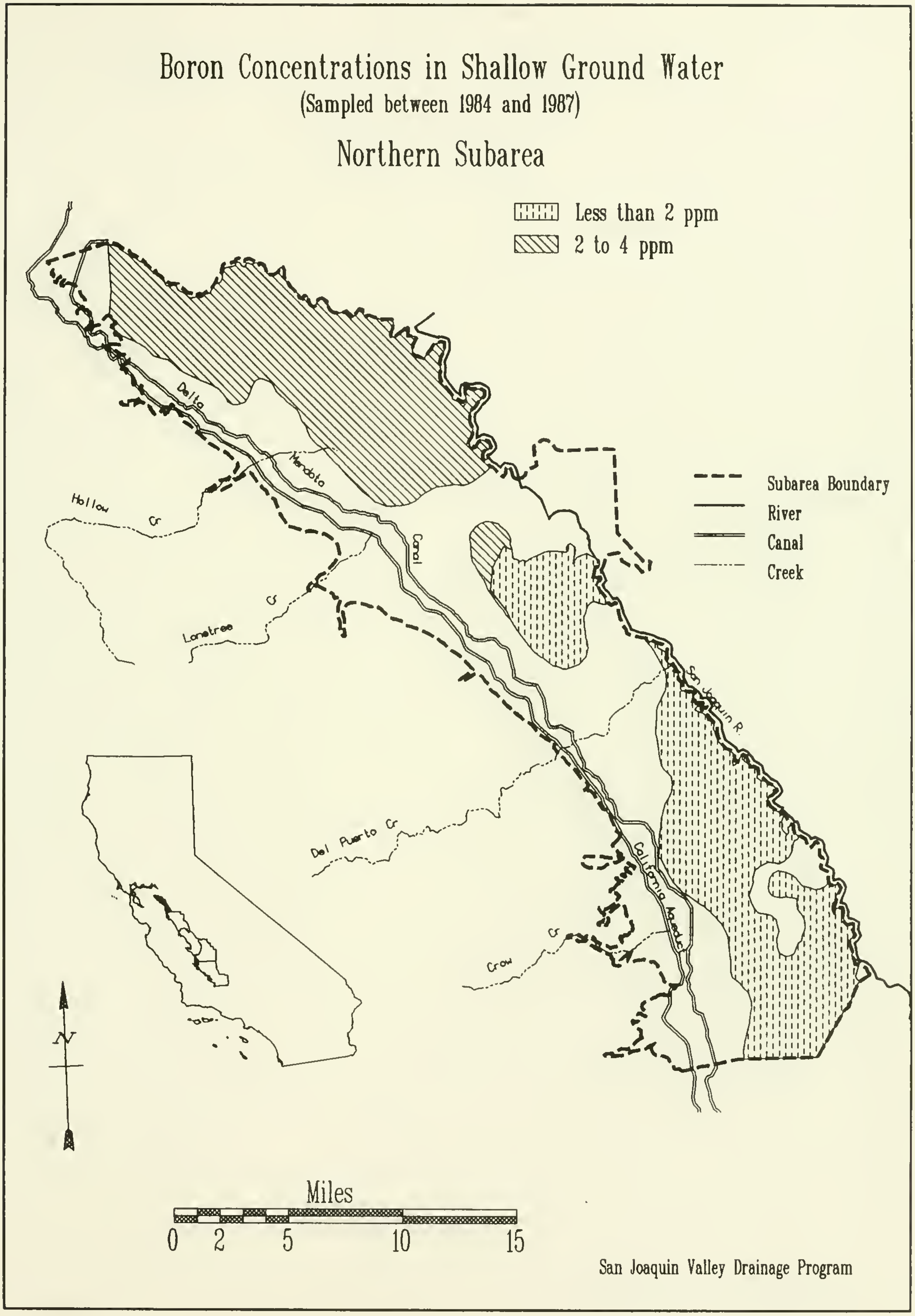
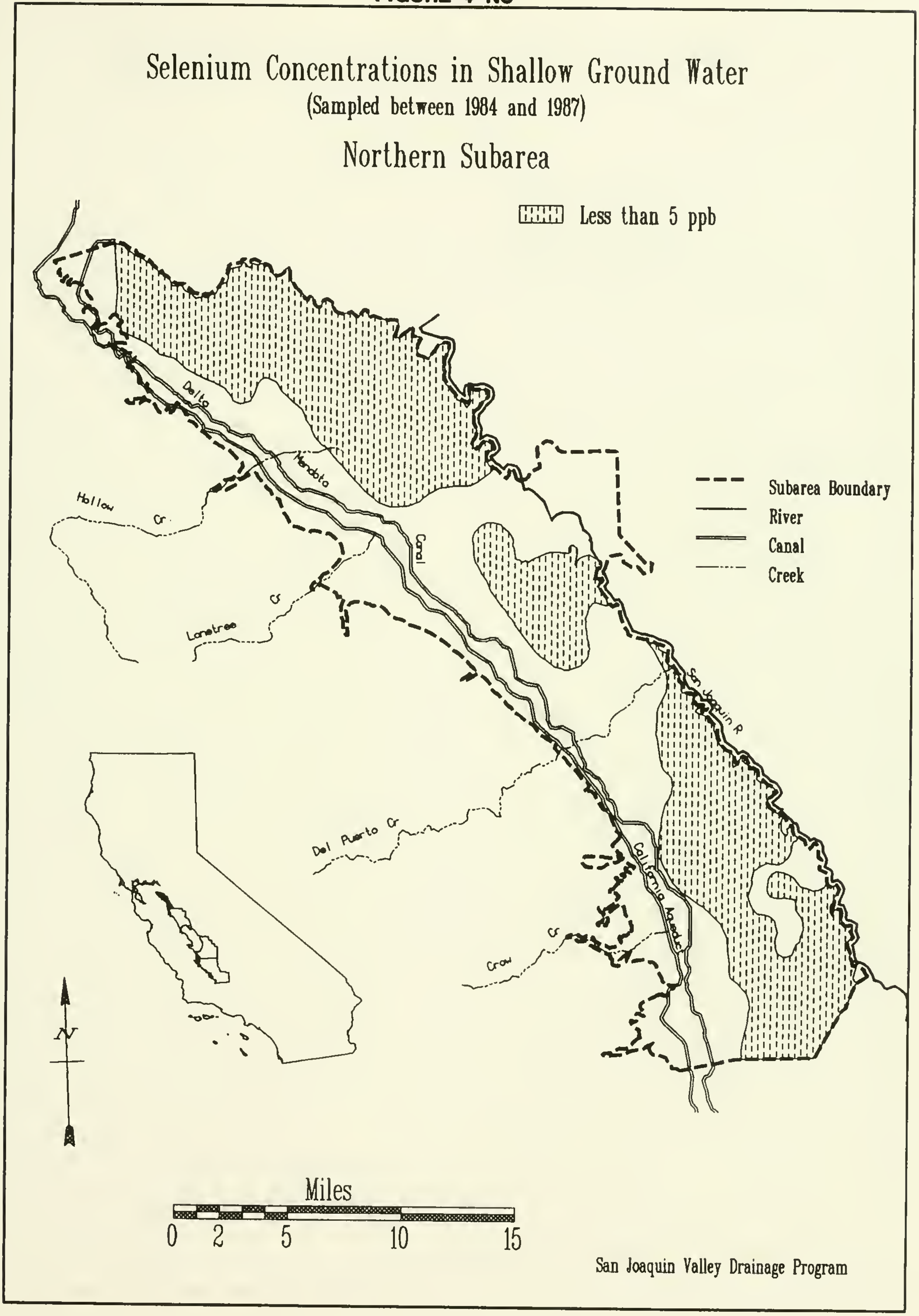

Electrical Conductivity of Shallow Ground Water
(Sampled between 1984 and 1987)
Northern Subarea
Less than 2500 microsiemens per cm
2500 to 5000 microsiemens per cm
5000 to 10000 microsiemens per cm
10000 to 20000 microsiemens per cm
(Conversion factor: 1000 microsiemens per cm equals approx. 650 ppm TDS)
Subarea Boundary
River
Canal
Creek
Delta
Mendota
Canal
Hollow
Cr
Lonetree
Cr
San Joaquin R
Del Puerto Cr
California Aqueduct
Crow
Cr
N
Miles
0
2
5
10
15
San Joaquin Valley Drainage Program

FIGURE 4-N4



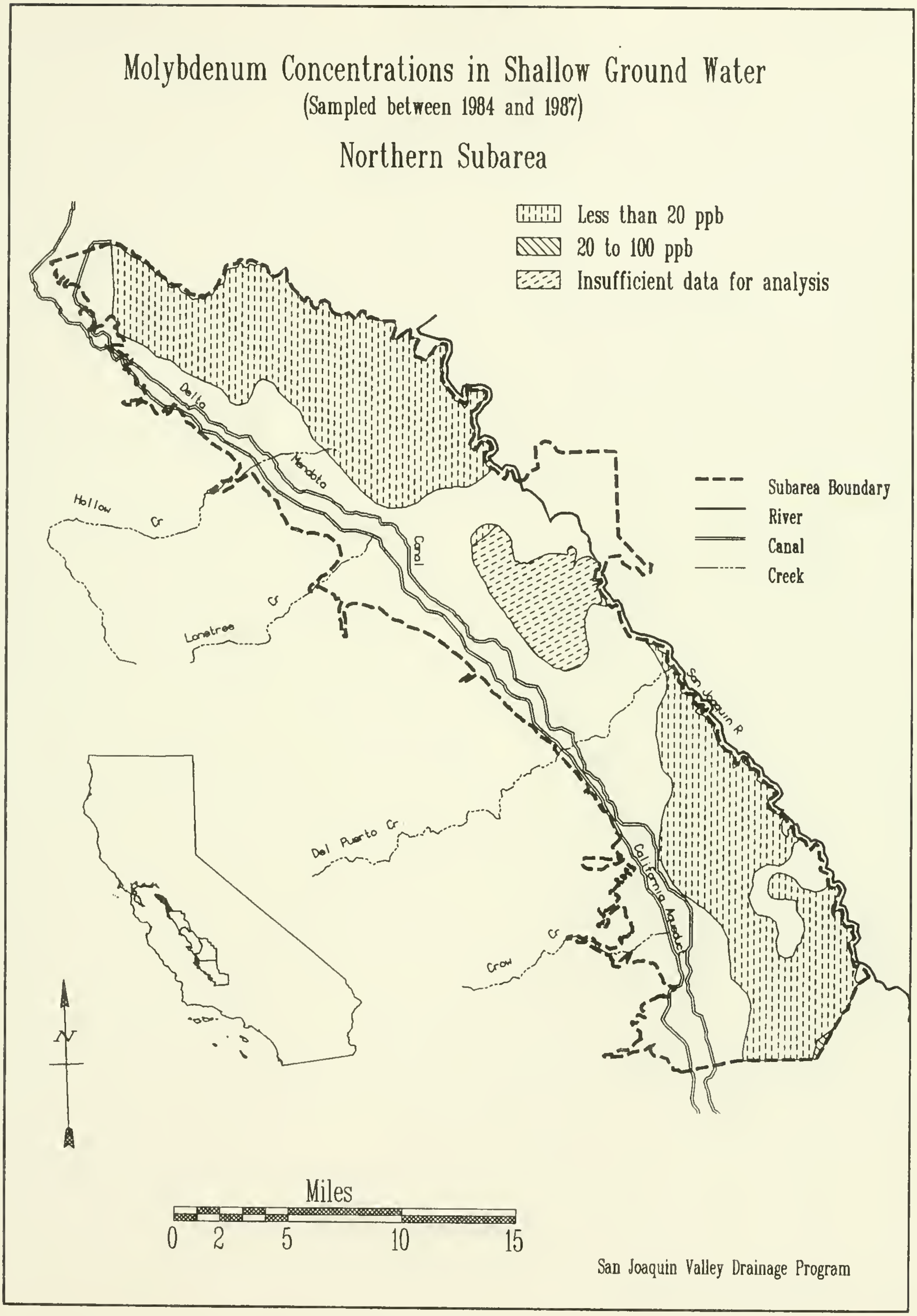
Boron Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Northern Subarea
Less than 2 ppm
2 to 4 ppm
Subarea Boundary
River
Canal
Creek
Delta
Mendota
Canal
Hollow Cr
Lonetree Cr
Del Puerto Cr
Crow Cr
California Aqueduct
San Joaquin R.
N
Miles
0
2
5
10
15
San Joaquin Valley Drainage Program

FIGURE 4-N5



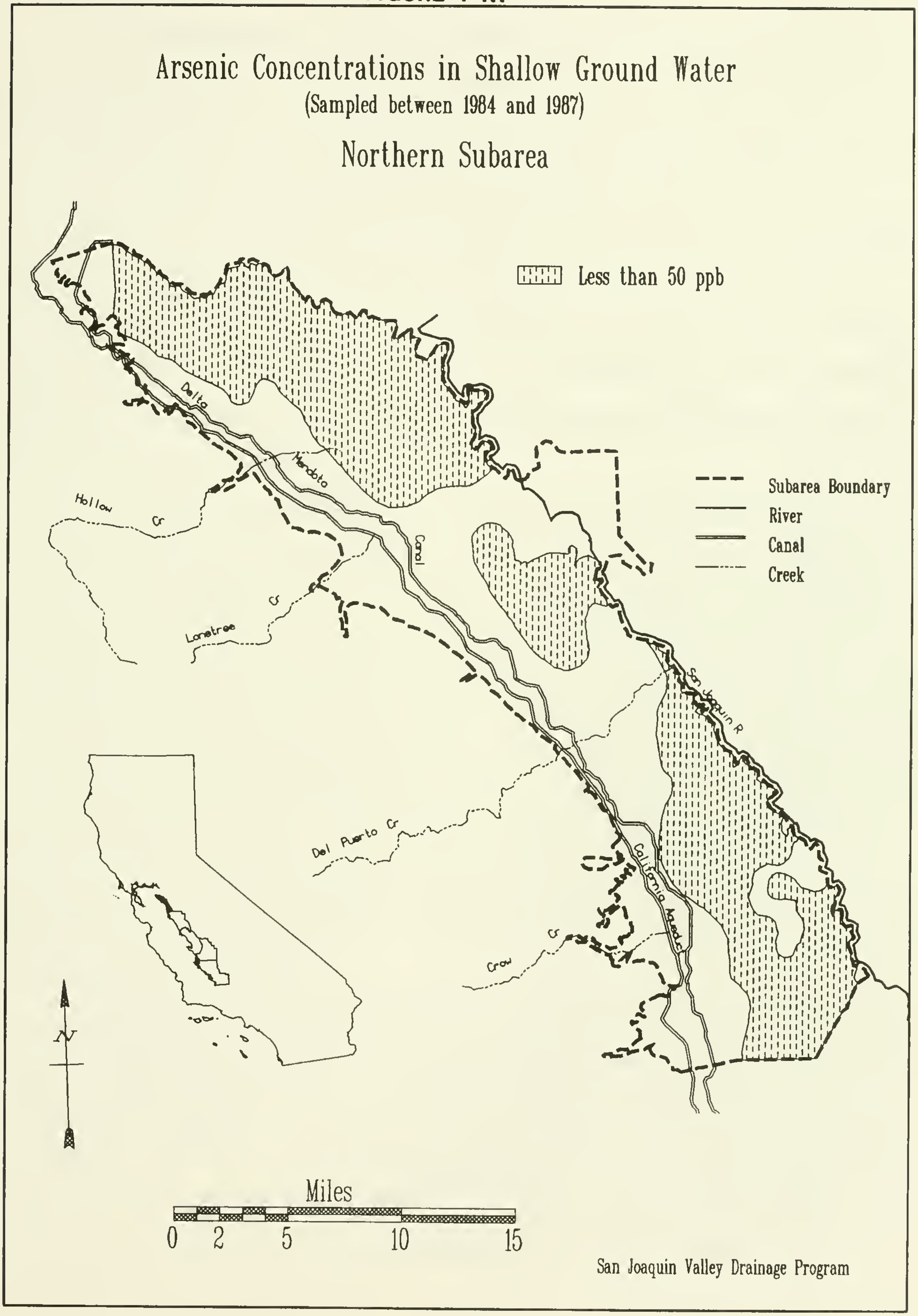
Selenium Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Northern Subarea
Less than 5 ppb
Subarea Boundary
River
Canal
Creek
Delta
Mendota
Canal
Hollow
Cr
Lonetree
Cr
San Joaquin R
Del Puerto Cr
California Aqueduct
Crow
Cr
N
Miles
0
2
5
10
15
San Joaquin Valley Drainage Program

FIGURE 4-N6



Molybdenum Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Northern Subarea
Less than 20 ppb
20 to 100 ppb
Insufficient data for analysis
Subarea Boundary
River
Canal
Creek
Delta
Mendota
Canal
Hollow Cr
Lonetree Cr
Del Puerto Cr
Crow Cr
California Aqueduct
San Joaquin R
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-N7


Arsenic Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Northern Subarea
Less than 50 ppb
Subarea Boundary
River
Canal
Creek
Delta
Mendota
Canal
Hollow
Cr
Lonetree
Cr
San Joaquin R
Del Puerto Cr
California Aqueduct
Crow
Cr
N
Miles
0
2
5
10
15
San Joaquin Valley Drainage Program

of dissolved contaminants. Additional dilution results from the operation of major surface storage facilities on the Stanislaus River. Water releases are made from New Melones Reservoir to maintain river water quality near Vernalis on the San Joaquin River, consistent with State water-quality criteria (including a limit of 500 ppm salt). A 1986 agreement between the South Delta Water Agency and the USBR provides for a 50-ppm reduction in the Vernalis criteria (to 450 ppm salt) during the irrigation season, as well as a minimum streamflow of 1,000 cubic feet per second. This agreement is interim, pending implementation of long-term solutions to assure compliance with water-quality requirements in the south Delta.

Agricultural drainage problems. Approximately 50,000 acres of agricultural land in this subarea has ground-water levels within 10 feet of the land surface during part of the year. The 10-foot depth is important in this subarea because of the prevalence of orchards, which are adversely affected by ground water at greater depths than are field and row crops.

Water-budget analyses indicate that, on a regional scale, the amount of land affected by shallow ground-water levels in the subarea is likely to remain relatively constant if present water-supply and drainage conditions continue. It is estimated that the salt load entering the subarea approximately equals the salt load leaving the subarea, and thus a salt balance has been achieved.

Planning objectives for agriculture. It is assumed that the San Joaquin River will continue to receive and convey subsurface drainage water from the subarea, and that there will be no regulatory attempt to halt ground-water seepage that, in places, is moderately saline. There are no specific planning objectives for solving drainage problems for agriculture in the Northern Subarea because of the relatively minor extent of those problems.

Public Health

Because levels of selenium and other substances of concern in shallow ground water and soils are comparatively low in this subarea, sampling of substances in the pathways of human exposure have not been conducted. Sampling and analyses would become necessary in the future if elevated concentrations of selenium or other potentially toxic substances are found in drainage water, shallow ground water, or soils.

Fish and Wildlife Resources

Description. With the exception of a few small towns, some military reservations, small parks, the San Joaquin River, and the recently established San Joaquin River National Wildlife Refuge, almost the entire remainder of the Northern Subarea is in agricultural land uses. The San Joaquin River provides critical habitat for chinook salmon migrating between east-side tributaries and the Delta, San Francisco Bay, and Pacific Ocean. The lower reaches of the river also provide habitat which supports striped bass, sturgeon, American shad, and other native, nongame fishes.

Acquisition of the newly established 10,295-acre San Joaquin River NWR (780 acres of which have been acquired to date) will involve fee simple purchase of most acres and purchase of conservation easements for some existing wetlands (in duck clubs). Development and management of the refuge will greatly increase the wildlife values of the subarea, especially for grasslands, wetlands, and riparian-dependent species, including: sandhill cranes, waterfowl, shorebirds, wading birds, aquatic mammals; and endangered or threatened species or candidates for such status, such as the Aleutian Canada goose, Western yellow-billed cuckoo, San Joaquin kit fox, riparian brush rabbit, and San Joaquin Valley woodrat.

Problems. As a result of operation of several large dams and associated canals on both the main stem and east-side tributaries (which store and divert waters primarily for agricultural, municipal, and industrial uses), the San Joaquin River carries substantially less freshwater than it did historically. In addition, it serves as an outlet to the Delta (and possibly San Francisco Bay and the ocean) for an increasing volume of drainage water produced by irrigated agricultural lands on the west side of the San Joaquin Basin. The majority of the subsurface drainage flow that passes through this subarea is produced in the Grasslands Subarea. As a result of out-of-basin water deliveries (e.g., through the Hetch Hetchy Aqueduct, Mokelumne Aqueduct, and Friant-Kern Canal), local water diversions (primarily for agricultural uses), and discharges of both surface and subsurface drainage waters, the quality of San Joaquin River flows in this reach has been significantly degraded (SWRCB, 1987; CVRWQCB, 1988a).

Instream fishery flow needs (especially for salmon) are not satisfied in this reach of the river during certain times of the year. Flows have been significantly reduced, salinity has significantly increased, and in the lower river, temperatures and nitrogen concentrations are elevated and dissolved oxygen concentrations are low. The amount of Delta water being pumped by the CVP and SWP occasionally exceeds an amount equal to about five times the channel flow in the San Joaquin River at Vernalis. When this condition occurs, the lower San Joaquin River flows upstream between Stockton and Old River, redirecting outmigrant salmon smolts toward the pumping plants.

As a result of dilution from east-side tributaries, concentrations of selenium in water and sediments in this reach of the San Joaquin River are

generally very low. Selenium concentrations in fish and wildlife food-chain organisms sampled to date do not exceed toxic concentrations. Instream fishery flow needs for this reach of the river have not yet been determined.

Very little native upland or wetland habitat remains in the Northern Subarea, and current values as wildlife habitat are low. Wildlife agencies and interests have determined that the Delta-northern San Joaquin Basin area is 20,000 acres short of the wetland habitat needed to support international waterfowl population objectives (USFWS, 1987; USFWS and Canadian Wildlife Service, 1986).

There have been no studies of drainage-related contamination of wildlife habitats in the Northern Subarea. It is unknown how much, if any, agricultural drainage water was previously used to help satisfy wildlife water needs in this subarea. Current firm water supplies for the San Joaquin River NWR total 16,800 acre-ft/yr, enough to satisfy only 53 percent of the new refuge's firm, nontoxic freshwater needs (pers. comm., Oct. 31, 1988, G. Zahm, Refuge Manager, USFWS, San Luis NWR, Los Banos, CA).

Objectives. Protection of remaining fisheries in the lower reach of the main stem San Joaquin River would require maintenance or improvement of water-quality and flow conditions. Existing wildlife habitat values would be protected and improved with acquisition and management of the new San Joaquin River NWR. Protection of the few remaining acres of riparian habitat in the Northern Subarea would help protect a broad diversity of resident, migratory, common, and rare species.

Additional biological monitoring and field and laboratory research are needed to fill in data gaps and determine, for example: what the concentrations of drainage contaminants are in water, sediments, and food-chain organisms in all fish and wildlife habitats in the subarea that are, or

have been, exposed to drainage water; and the quantity, quality, and schedule of instream fishery flows needed in this reach of the San Joaquin River to support a viable fishery.

Concentrations of drainage-water contaminants in fish and wildlife habitats in this subarea are generally quite low, and there are apparently no drainage water-related adverse effects on fish or wildlife. Therefore, no decontamination and restoration objectives have been established. Additionally, because no data are available regarding use of agricultural drainage water by wildlife in this subarea, no objectives have been established for substitute water supplies.

According to information presented by the DFG at the 1987 Bay-Delta water quality hearings, fishery resources in this subarea would be improved if either of the following actions were taken: freshwater flows in the main stem San Joaquin River were increased (water-quality and water-quantity problems and associated salmon migration problems would be substantially reduced by maintaining a flow of 5,000 cubic feet/second during the critical downstream migration period [December through June] for juveniles); and/or a positive flow past the Old River/San Joaquin River bifurcation was provided (sufficient to maintain the concentration of dissolved oxygen in the Stockton Ship Channel greater than 5 ppm). Improvement of wildlife resources in this subarea would occur if: the new San Joaquin River NWR was provided with an additional firm, nontoxic, freshwater supply of 15,000 acre-ft/yr (equal to the additional water needed to satisfy optimum management objectives for the refuge); and/or 20,000 acres of new wetlands and associated water supplies was provided in the subarea.

Available Technologies Alternative

Because of the relatively minor extent of drainage and drainage-related problems in this subarea, no agricultural, public health, and fish and wildlife planning objectives were established and an alternative plan was not developed. However, actions to protect, restore, and provide substitute water supplies for fish and wildlife resources in this subarea have been identified.

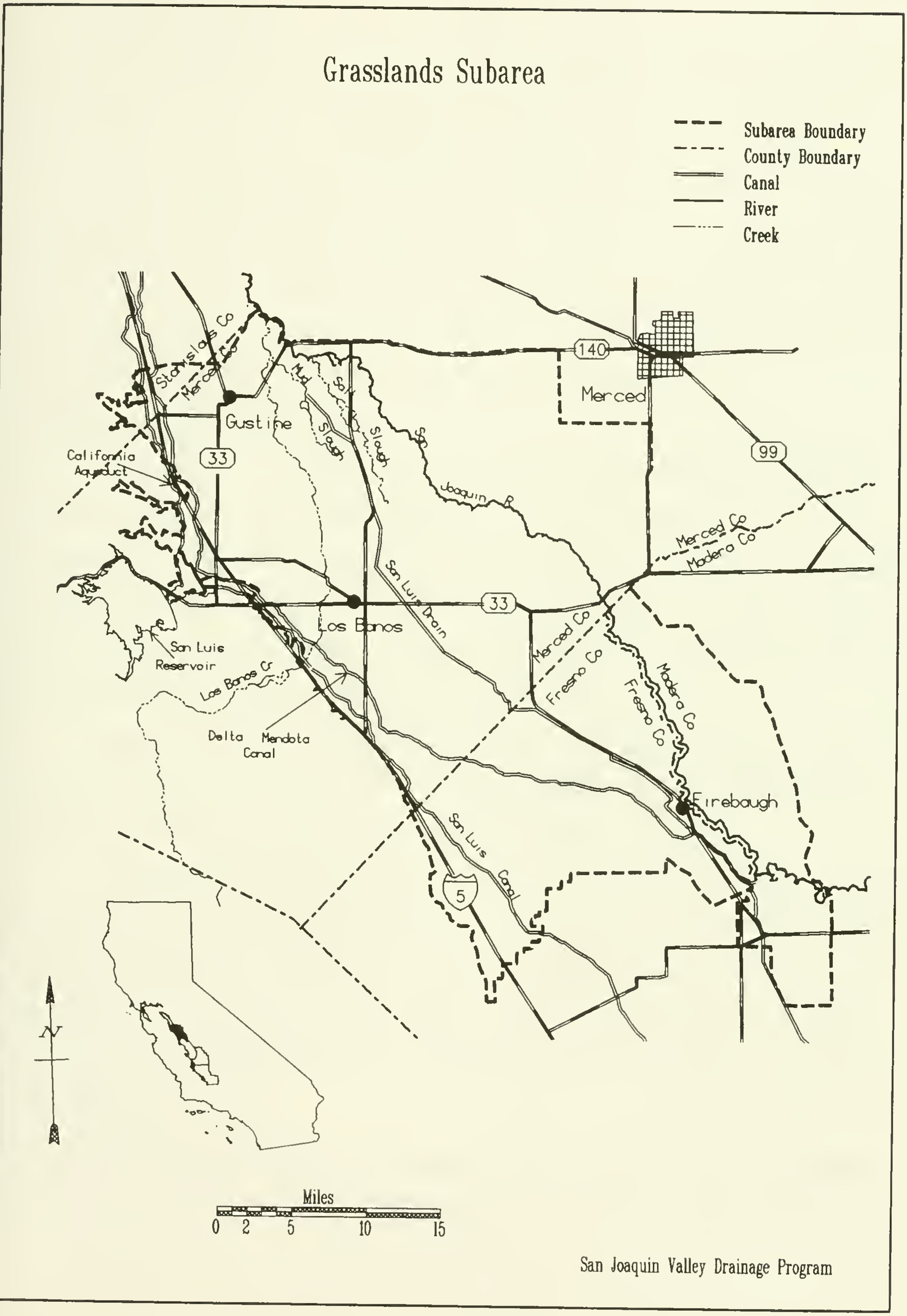
Water flow and water quality in the San Joaquin River has been and continues to be degraded by diversions and out-of-basin water exports and by discharge of untreated subsurface agricultural drainage waters. Protection of existing fisheries in the Northern Subarea could occur through improvement of water quality and flow through reduction in the discharge of agricultural drainage water and/or provision of additional instream freshwater flows.

Protection of existing wildlife resources in the Northern Subarea could occur through continuation of ongoing efforts by the USFWS to acquire and manage or otherwise legally protect approximately 10,000 acres of remaining unprotected grassland, wetland, and riparian habitats within the boundaries of the newly designated San Joaquin River NWR.

GRASSLANDS SUBAREA

The Grasslands Subarea (Figure 4-G1) includes about 1,105 square miles (707,000 acres) of predominantly rural land in western Merced and northwestern Fresno Counties. The subarea is about 45 miles long and 25 miles wide and extends from about Gustine in the north to below Firebaugh in the south. The eastern boundary encloses most of the wetlands and grasslands lying along the San Joaquin River; the western boundary lies along the base of the Coast Range foothills. The major land use is irrigated agriculture.

FIGURE 4-G1


Grasslands Subarea
Subarea Boundary
County Boundary
Canal
River
Creek
Stanislaus Co
Merced Co
Gustine
Merced
140
99
33
California Aqueduct
Salt Slough
Mud Slough
San Joaquin R
San Luis Drain
Los Banos
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
Merced Co
Madera Co
Fresno Co
Firebaugh
San Luis Canal
5
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

A few communities such as Los Banos are experiencing moderate growth due to residential overflow from the Santa Clara Valley and increased food processing. The estimated 1989 population of the subarea is 36,000.

Areas identified as having potential drainage problems are irrigated agricultural lands located primarily in the southern and southwestern parts of the subarea. There also are large tracts of seasonal and permanent wetlands in the subarea. High water-table conditions are desirable in wetland areas, and they are flooded during at least part of the year.

Irrigated Agriculture

Water supply. Irrigation water supplies in the Grasslands Subarea consist of Delta imports, diversions from the San Joaquin River and tributaries, and local ground water. Delta water is conveyed to the subarea through the Delta-Mendota and San Luis Canals. The annual firm irrigation water supply is about 1,150,000 acre-feet: 1 million acre-feet from the Delta and 150,000 acre-feet from ground water.

There are 22 water districts and several drainage districts in the subarea, ranging in size from one district representing a single farm to a district representing more than 1,800 water users.

Drainage-related water quality. Figure 4-G2 shows shallow ground water at depths of 0-5, 5-10, and 10-20 feet below the land surface in 1987. The shallow ground water contains a wide range of salt, boron, selenium, molybdenum, and arsenic concentrations. The areal distribution of these dissolved constituents is shown in Figures 4-G3, 4-G4, 4-G5, 4-G6 and 4-G7, respectively.

Subsurface agricultural drainage, which discharges to Salt and Mud Sloughs and the San Joaquin River, degrades river water quality primarily in

terms of salt, boron, and selenium. The salt and contaminant loads are described in the SWRCB Technical Committee report "Regulation of Agricultural Drainage to the San Joaquin River," dated August 1987.

In 1981, which was a critically dry water year, inflow through Mud and Salt Sloughs accounted for 81 percent of the selenium load, 60 percent of the boron load, and 46 percent of the salt load to the San Joaquin River at Hills Ferry. Until 1985, drainage water was discharged directly into Mud or Salt Sloughs or was diverted by Grassland Water District (GWD) for use on wetland habitat prior to discharge into the sloughs. Since late 1985, only small amounts of drainage water, with low contaminant levels, have been diverted to wetlands. The subarea now contributes about 52 percent of the total salt load of the San Joaquin River during low-flow periods.

Agricultural drainage problems. Approximately 218,000 acres of agricultural land in this subarea has ground-water levels within 5 feet of the land surface during part of the year (excluding about 90,000 acres of wetland and wildlife habitat areas).

Water-budget analyses indicate that, on a regional scale, the amount of land affected by shallow ground-water levels in the subarea is likely to remain relatively constant if present water supply and drainage conditions continue. However, the salt load in the shallow ground water is accumulating at a rate of about 100,000 tons/year.

Although shallow ground-water levels in the subarea seem to have stabilized, the present high water-table conditions impair water quality, crop selection, and crop productivity.

Annual problem-water volumes have been estimated for each water-quality zone in this subarea. (See Table 4-3 and Figure 4-G8.)

FIGURE 4-G2

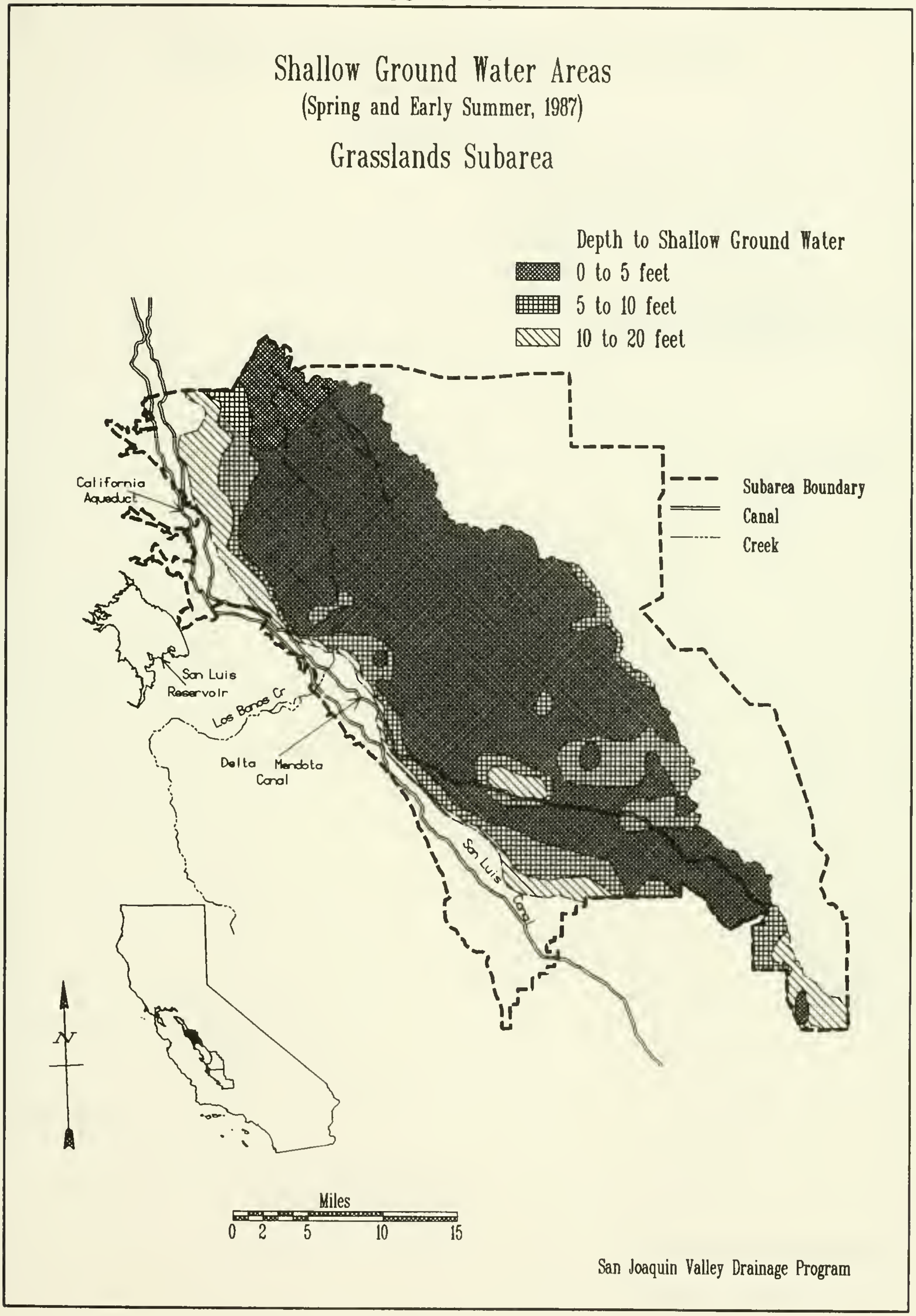

Shallow Ground Water Areas
(Spring and Early Summer, 1987)
Grasslands Subarea
Depth to Shallow Ground Water
0 to 5 feet
5 to 10 feet
10 to 20 feet
Subarea Boundary
Canal
Creek
California Aqueduct
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
San Luis Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-G3

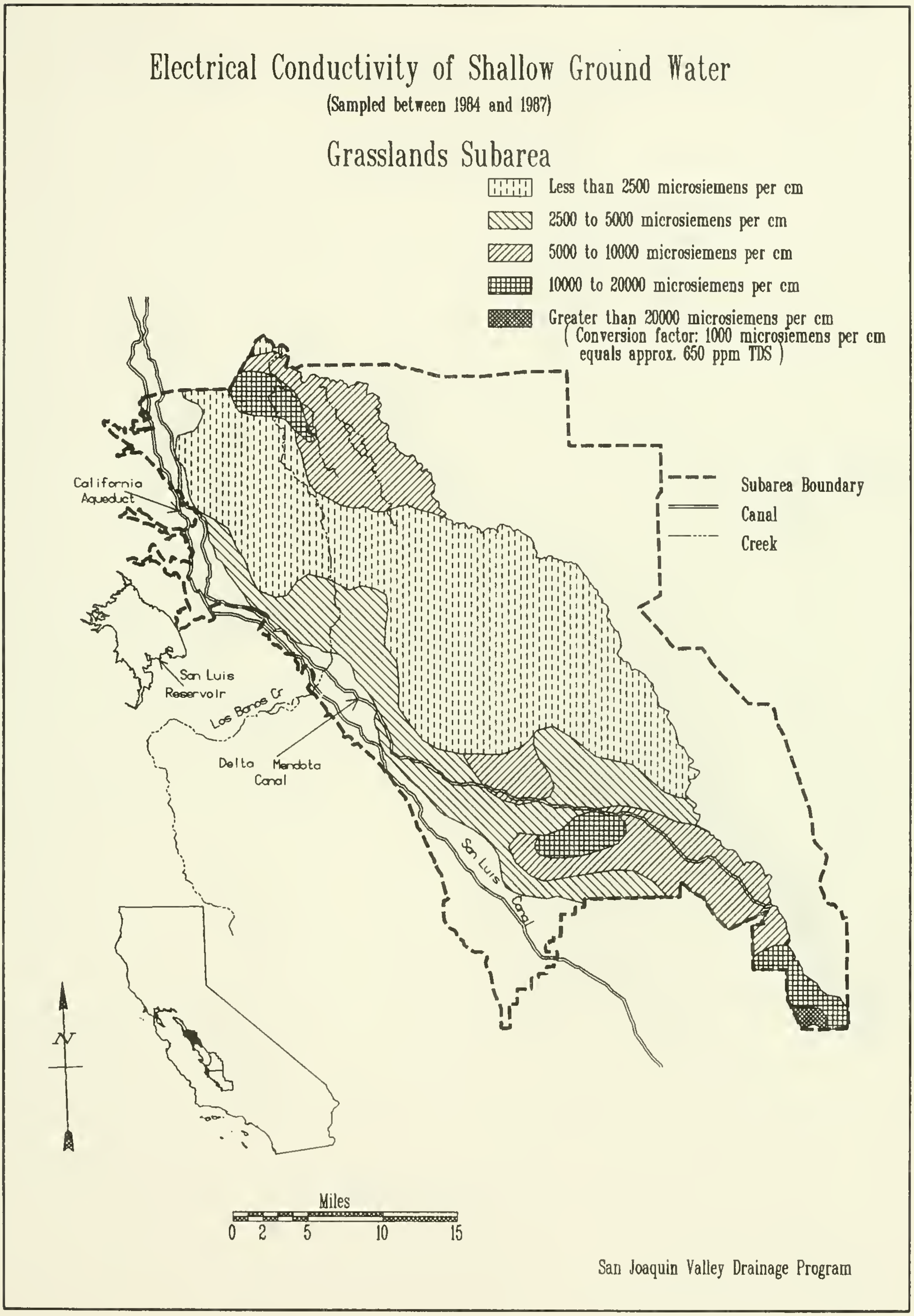

Electrical Conductivity of Shallow Ground Water
(Sampled between 1984 and 1987)
Grasslands Subarea
Less than 2500 microsiemens per cm
2500 to 5000 microsiemens per cm
5000 to 10000 microsiemens per cm
10000 to 20000 microsiemens per cm
Greater than 20000 microsiemens per cm
(Conversion factor: 1000 microsiemens per cm equals approx. 650 ppm TDS)
Subarea Boundary
Canal
Creek
California Aqueduct
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
San Luis Canal
N
Miles
0
2
5
10
15
San Joaquin Valley Drainage Program

FIGURE 4-G4

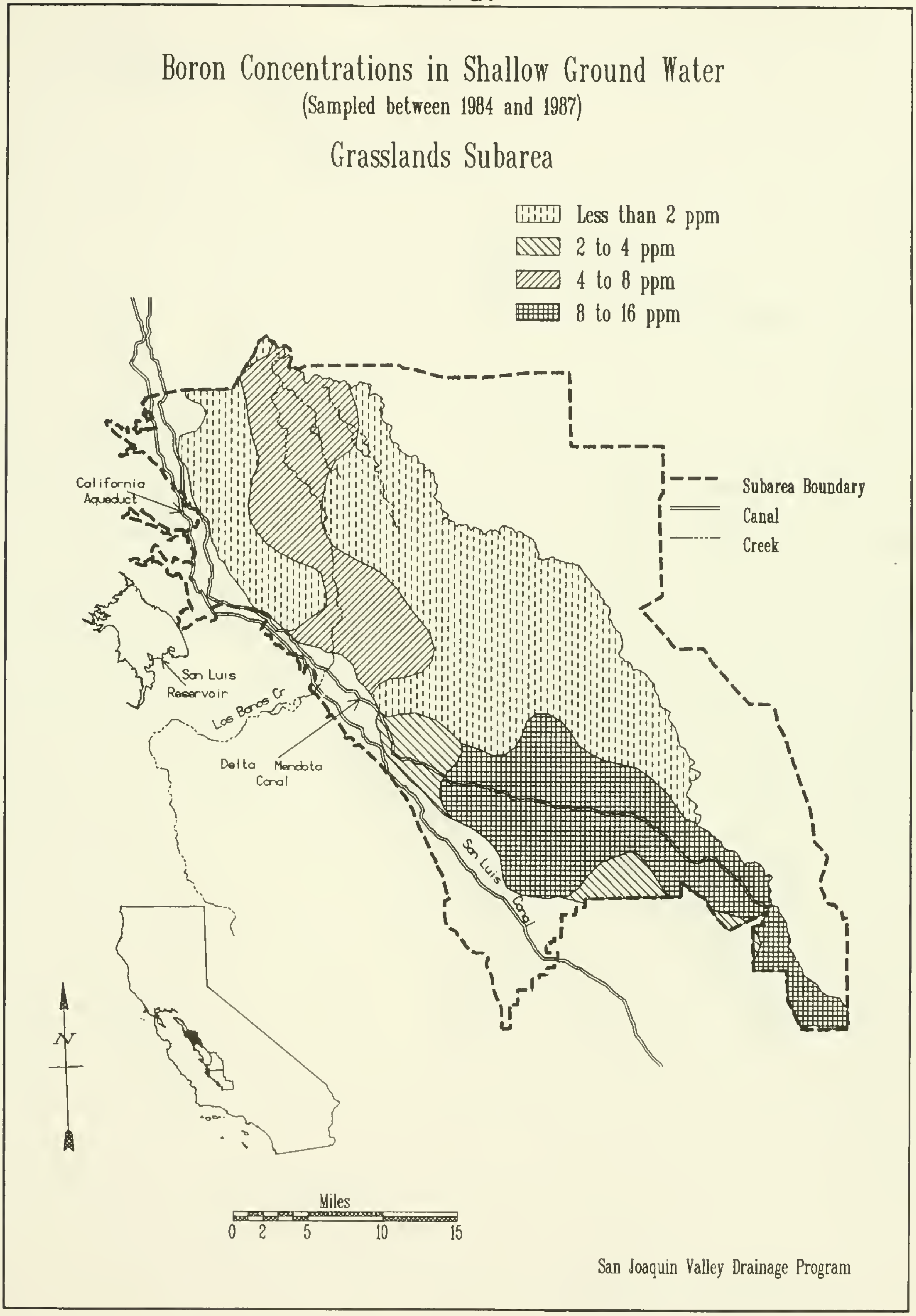

Boron Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Grasslands Subarea
Less than 2 ppm
2 to 4 ppm
4 to 8 ppm
8 to 16 ppm
Subarea Boundary
Canal
Creek
California Aqueduct
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
San Luis Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-G5

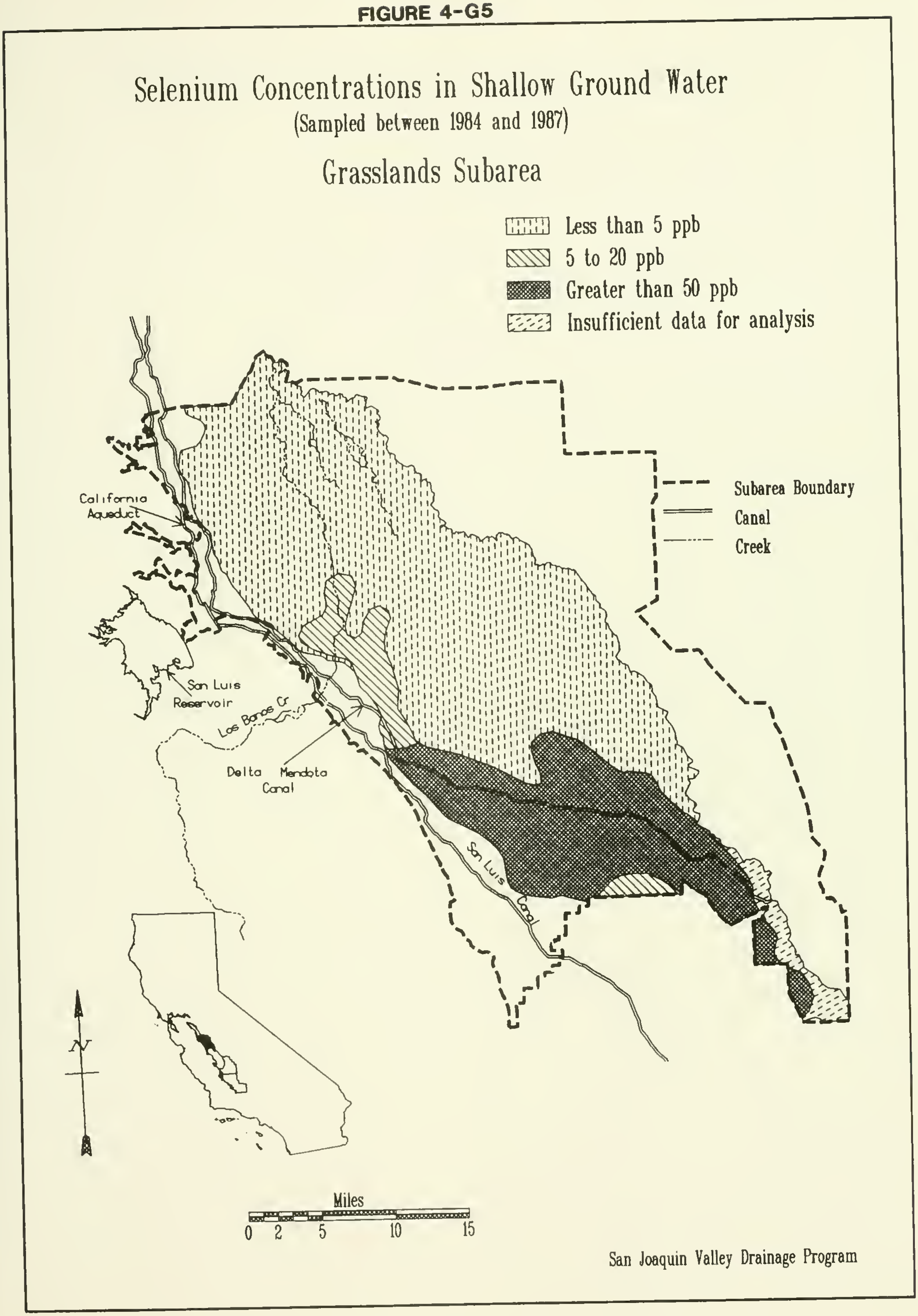
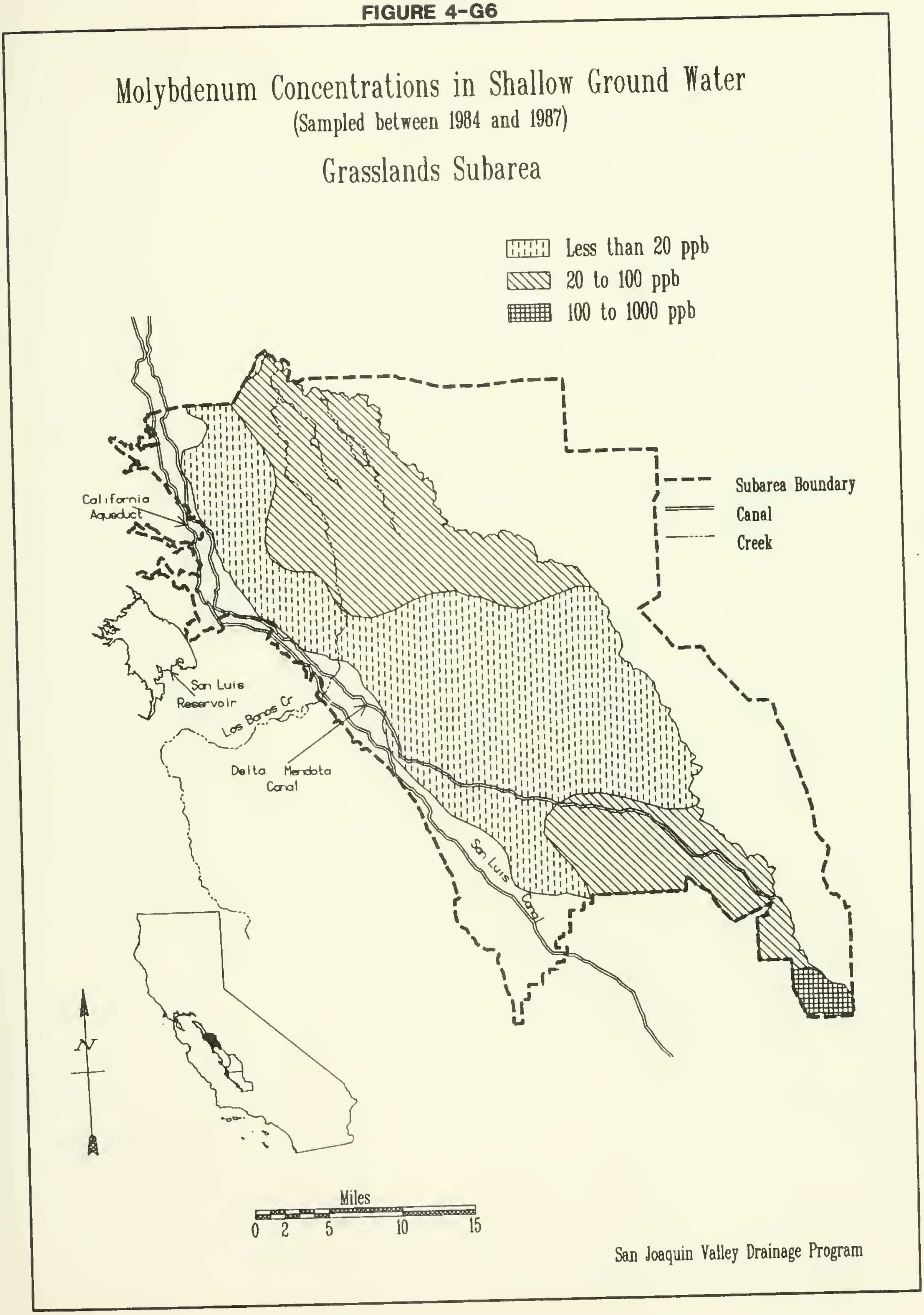

Selenium Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Grasslands Subarea
Less than 5 ppb
5 to 20 ppb
Greater than 50 ppb
Insufficient data for analysis
Subarea Boundary
Canal
Creek
California Aqueduct
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
San Luis Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-G6



Molybdenum Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Grasslands Subarea
Less than 20 ppb
20 to 100 ppb
100 to 1000 ppb
Subarea Boundary
Canal
Creek
California Aqueduct
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
San Luis Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4G-7

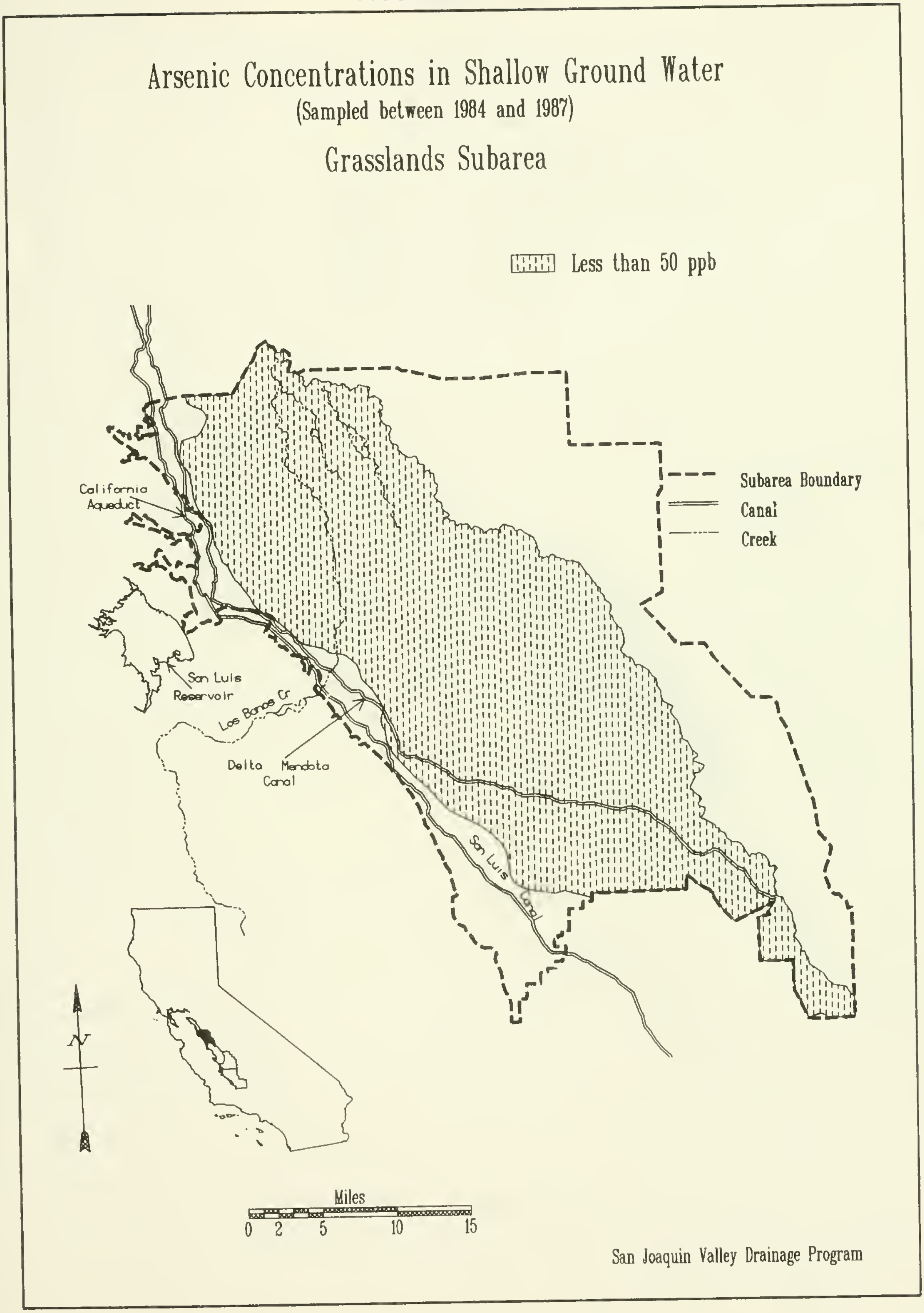

Arsenic Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Grasslands Subarea
Less than 50 ppb
Subarea Boundary
Canal
Creek
California Aqueduct
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
San Luis Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-G8

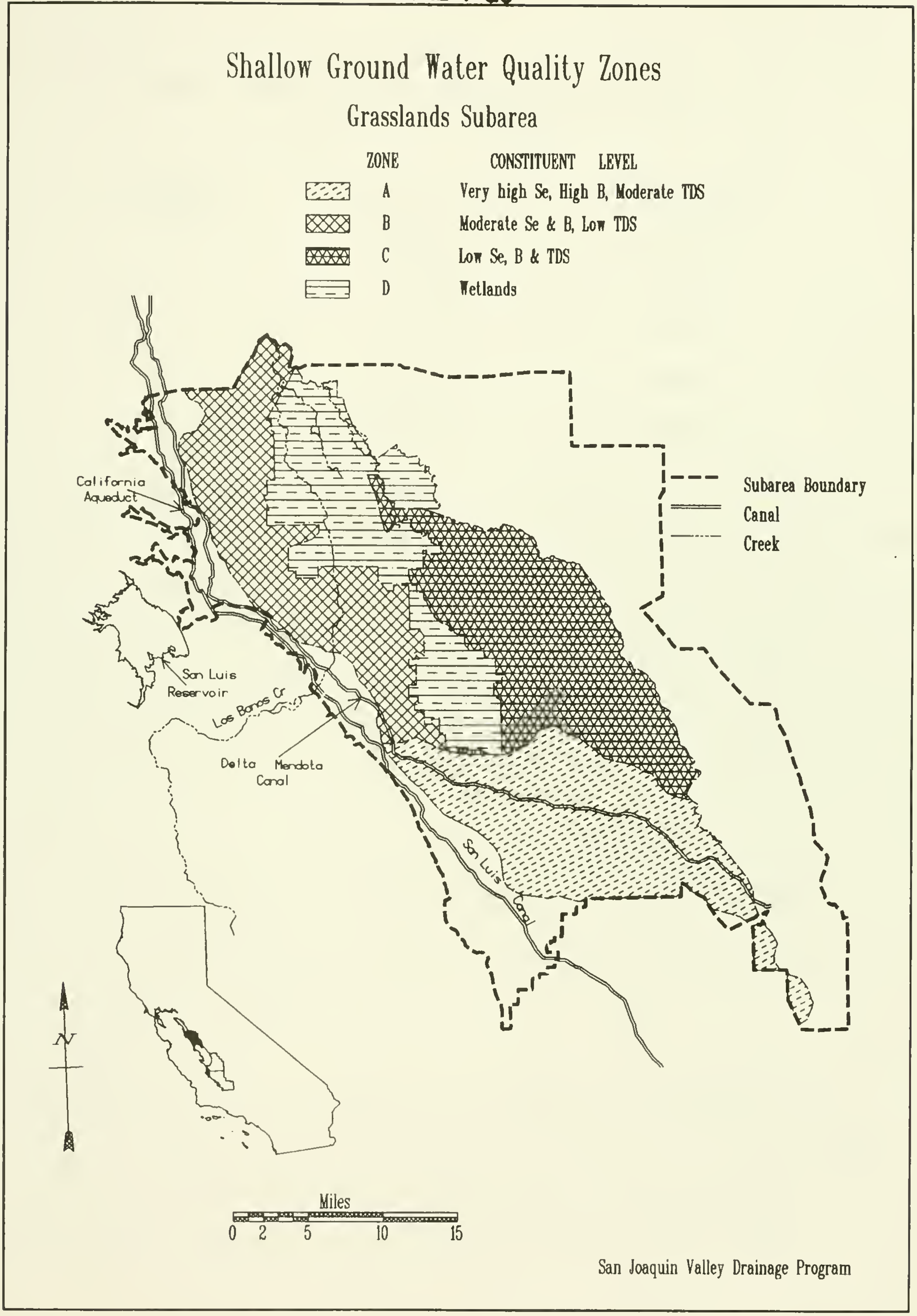

Shallow Ground Water Quality Zones
Grasslands Subarea
ZONE
CONSTITUENT LEVEL
A
Very high Se, High B, Moderate TDS
B
Moderate Se & B, Low TDS
C
Low Se, B & TDS
D
Wetlands
Subarea Boundary
Canal
Creek
California Aqueduct
San Luis Reservoir
Los Banos Cr
Delta Mendota Canal
San Luis Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

Table 4-3

ANNUAL PROBLEM-WATER VOLUME - GRASSLANDS SUBAREA
(For Year 2000)

Water-Quality Zone	Drained Area (acres)	Drainage-Water Volume (acre-ft)
A	72,000	53,000
B	14,000	11,000
C	30,000	22,000
TOTAL	116,000	86,000

Planning objectives for agriculture. For planning purposes, it is assumed that the amount of land drained will more than double by the year 2000, as growers act to manage or control shallow ground water. The objective for the Grasslands Subarea is to dispose of or manage the problem-water volume shown in Table 4-3 by a combination of source-control and other appropriate measures so the drainage water is not a problem to agriculture or to other public values (e.g., water quality, public health, and fish and wildlife).

The average selenium concentrations in Zones A and B exceed the water-quality objectives proposed for the San Joaquin River (see Chapter 2), thus constraining drainage discharge to the San Joaquin River or its tributaries without dilution or treatment.

Public Health

Conditions. Crops and livestock in the subarea have been sampled for unsafe levels of selenium; unsafe levels have not been found. Although crops and livestock do not currently pose a health threat, human exposure to potentially toxic contaminants in agricultural drainage waters in the

Grasslands Subarea may be higher than in the other subareas. There is apparently no quantitative information available on direct human uses (e.g., swimming, bathing, drinking, cooking) of surface waters in the subarea. Hazards due to consumption of wildlife at posted areas, such as Kesterson, have probably been diminished by remedial actions. However, a potential hazard exists along the San Luis Drain. The drain is posted, forbidding trespassing, fishing, and hunting, with a warning of potential health risk from selenium contamination.

According to a 1987 survey by Campbell and Christensen (1989), "a large number and variety of people forage" in the Grasslands Subarea. Foraging included "hunting, fishing, trapping, clamming, frogging, and the collection of crayfish and edible plants," and its frequency was dependent upon the seasonal availability of wild food items. Foraging activities in and around irrigation canals and agricultural drains in the subarea were similar. Campbell and Christensen further noted that approximately 61 percent of Southeast Asians surveyed have foraged or currently forage in the subarea, but foraged food made up only a small portion of their total family diets. Campbell and Christensen believed that wild foods also made up similar portions of family diets for other ethnic groups foraging in the subarea.

Chemical analyses of edible wild foods collected from the Grasslands Subarea reveal concentrations of selenium in excess of 2 ppm wet weight (equal to about 6-12 ppm dry weight), which the California Department of Health Services (CDHS) has established as an interim guidance level for consideration or issuance of human health advisories (Fan et al., 1988). Wild foods containing selenium concentrations in excess of the CDHS selenium action level in the subarea (outside of Kesterson Reservoir) include: mallard collected

from Bovet Gun Club (J. Beam, CDFG, Los Banos, CA [unpublished data]); green sunfish, channel catfish, and freshwater clams collected from Camp 13 Ditch (Saiki, 1985a; Tamplin and Volz, 1985; White et al., 1987); American coot and snow goose collected from Cooke Duck Club (P. Chadwick, DFG, Stockton, CA [unpublished data]); cinnamon teal, mallard, northern pintail, and ruddy duck collected from Gables Duck Club (P. Chadwick, DFG, Stockton, CA [unpublished data]); bluegill, green sunfish, and Sacramento blackfish collected from Helm Canal (Saiki, 1985a); mallard and northern shoveler collected from Los Banos WA (J. Beam, DFG, Los Banos, CA [unpublished data]; P. Chadwick, DFG, Stockton, CA [unpublished data]); black bullhead, bluegill, common carp, and green sunfish collected from Mud Slough (Saiki, 1985a); common carp collected from San Luis Canal (Saiki, 1985b); widgeongrass, channel catfish, common carp, and Sacramento blackfish collected from the San Luis Drain (Saiki, 1986; Saiki and Lowe, 1987); and American coot collected from Santa Cruz Duck Club (P. Chadwick, DFG, Stockton, CA [unpublished data]).

Three drainage-water evaporation ponds are located in this subarea. There appear to be only limited biological residue data collected in October 1988 from one of these ponds (Souza) and no samples of edible wild foods which exceed the CDHS selenium action level (T. Heyne, CSUF, and M. Kie, CDFG, Fresno, CA [unpublished data]).

Information assembled by the SJVDP reveals that since 1984 a number of fish and wildlife and public-land managers and public-health officials have posted or issued 14 selenium-related fish and wildlife health warnings for the Grasslands Subarea. Those warnings advised the public (especially children, women of childbearing age, and pregnant women) to limit or discontinue their consumption of wild plants, fish, and/or wildlife from waterways and public and private wetlands in the Grasslands area.

Objectives. Actions should be taken to minimize potential drainage-related public health problems associated with consumption of fish and wildlife from drainage-contaminated waterways and wetlands in the Grasslands Subarea. The public health objectives for this subarea are to: (1) Restore (decontaminate) any habitat that would likely prove harmful to humans, (2) conduct both biological and chemical monitoring of existing habitats and any new habitats that might be created in attempts to solve the drainage problem or manage drainage-water discharges (e.g., new evaporation ponds), and (3) monitor potential human exposure sources for additional substances of concern and continue to monitor selenium in local produce to assure safe concentrations. The objective of monitoring is to compare existing selenium levels with background levels and public health action thresholds, creating basic information for risk determination and possible warnings and closures.

Fish and Wildlife Resources

Description. There is a larger area (approximately 110,000 acres representing about 16 percent of all the land in the subarea) managed primarily for fish and wildlife resources and associated public uses in the Grasslands Subarea than in any other subarea. There are three national wildlife refuges in the subarea (Kesterson, San Luis, and Merced NWR's, totaling almost 22,200 acres [acreage figure is the total of authorized boundaries and includes some currently unacquired areas]); four California wildlife areas (O'Neill Forebay, Volta, Los Banos, and Mendota WA's, totaling almost 20,600 acres); approximately 2,700 acres of California Department of Parks and Recreation land which has been proposed for State reserve status (San Luis Island); and about 200 private duck clubs (totaling approximately 60,000-70,000 acres). These public and private wildlife areas provide

critical wintering and some breeding habitat for millions of migratory birds of the Pacific Flyway, and valuable year-round habitat for a diversity of other wildlife species such as sandhill cranes, waterfowl, shorebirds, wading birds, aquatic mammals, and the endangered Aleutian Canada goose, Western yellow-billed cuckoo, and San Joaquin kit fox. Current populations of these species depend upon the remaining grassland, wetland, and riparian habitats in the Grasslands Subarea.

Historic chinook salmon runs of the upper San Joaquin River below Friant Dam have been eliminated due to inadequate instream flows below the dam. The sloughs and streams in the subarea support substantial numbers of resident fishes (e.g., bluegill, carp, black bullhead, and Sacramento blackfish [Saiki, 1984]) that are the basis of a significant sport, subsistence, and commercial fishery (Campbell and Christensen, 1989).

Acquisition of additional lands for Merced NWR (currently 780 acres) and San Luis NWR (currently 5,510 acres) and perpetual wetlands easements in the Grasslands area (about 50,000 acres) has been approved by the Director of the USFWS (Gritman, 1987; Stieglitz, 1985). Development and management of new lands will greatly increase the wildlife habitat values of the subarea, especially for species dependent upon grassland, wetland, and riparian habitats.

Newly created habitats in the subarea include three drainage-water evaporation ponds developed during the past 4 years (covering a total of about 51 acres, about 1 percent of all the evaporation pond acreage in the valley). The evaporation ponds are heavily used by aquatic birds for wintering and breeding habitat (Barnum, 1989; Hoffman-Floerke, 1985; Schroeder et al., 1988; Tribbey, 1988; Tribbey and Beckingham, 1986).

Problems. Contamination field studies have documented elevated concentrations of selenium (an indicator of contamination by subsurface drainage water) in water (greater than 5 ppb) and/or sediments (greater than 0.5 ppm, dry weight) collected from a number of areas in the Grasslands Subarea (in addition to Kesterson Reservoir and San Luis Drain) including: Mud Slough (North), Salt Slough, San Luis Canal, Santa Fe Grade Canal, Agatha Canal, Camp 13 Ditch, Charleston Ditch, Helm Canal, Main Canal, San Joaquin River, and duck clubs in the northwestern Grasslands area (DWR, 1988 [unpublished data from Water Data Information System], Fresno, CA; Clifton and Gilliom, 1989; SWRCB, 1987; James et al., 1988; Paveglio and Clark, 1988; Presser and Barnes, 1985; Shelton and Miller, 1988; USBR, 1987). Concentrations of selenium toxic to mallards (equal to or greater than 7 ppm, dry weight) have been found in food-chain organisms collected from San Luis NWR, Los Banos WA, Mud Slough (North), Santa Fe Grade Canal, Agatha Canal, Camp 13 Ditch, Helm Canal, Main Canal, and duck clubs in the southwestern Grasslands area (Ohlendorf et al., 1987; Paveglio and Bunck, 1987; Saiki, 1985b; Tamplin and Volz, 1985).

Subsurface drainage water was previously used to satisfy a substantial portion of the water needs for public and private wildlife areas in the Grasslands Subarea. Use of drainage water on all public and private wildlife areas during the late 1970's to mid-1980's in this area was approximately 129,000 acre-ft/yr (about 54 percent of all firm water supplies used on these areas). Most wildlife areas and duck clubs in the Grasslands area have discontinued use of agricultural drainage water due to contaminant threats posed to fish and wildlife. However, the same raw (untreated) drainage water that used to pass through (and be cleansed by) wetlands in the western

Grasslands area enroute to the San Joaquin River is now being discharged directly into drainage ditches, canals, Mud Slough (North), Salt Slough, and other tributaries to the river. As a result, the San Joaquin River in the Grasslands Subarea is currently receiving increased flows of subsurface drainage water.

Data collected by the SJVDP reveals that existing wildlife areas in the Grasslands Subarea need approximately 360,000 acre-ft/yr of firm, nontoxic freshwater to satisfy optimum management objectives. Reliable supplies of nontoxic freshwater for public and private wildlife areas in the Grasslands Subarea currently total approximately 112,000 acre-ft/yr (about 31 percent of needs).

Wildlife agencies and interests have determined that the middle and southern San Joaquin Basin area is 25,000 acres short of the wetland habitat needed to support international waterfowl population objectives (USFWS, 1987; USFWS and Canadian Wildlife Service, 1986).

Instream fishery flow needs (especially for chinook salmon) are currently not being satisfied. In addition, unnaturally high flows of drainage water entering the San Joaquin River from the west side of the valley (through Mud and Salt Sloughs) are attracting upstream-migrating adult chinook salmon into these sloughs instead of the Merced River. Concentrations of drainage-water contaminants are elevated, and there is no spawning or rearing habitat in these west-side sloughs.

Three drainage-water evaporation ponds exist in the Grasslands Subarea: Britz South Dos Palos (42 acres), Lindemann (under construction), and Souza (9 acres). Elevated concentrations of selenium have been discovered in water and sediments at Britz South Dos Palos evaporation pond (Westcot et al.,

1988a). The SJVDP is not aware of selenium data for water or sediments from the Souza and Lindemann ponds. Selenium analyses of biological samples collected from Souza evaporation pond did not exceed concentrations toxic to wildlife (T. Heyne, CSUF, and M. Kie, CDFG, Fresno, CA [unpublished data]). There appears to be no biological selenium data for Britz South Dos Palos or Lindemann evaporation ponds. No contaminant-related studies of reproduction or survival of wildlife have been conducted at any of these ponds.

It is currently unknown whether agroforestry plantations in the subarea are contaminated by drainage-water substances of concern such that they pose a contaminant threat to wildlife using the sites.

Objectives. Protection of existing fisheries in the main stem San Joaquin River will require: maintenance or improvement of water-quality and flow conditions; and reduction of discharge of drainage water into surface waters that have fisheries values (including the San Joaquin River) consistent with water-quality objectives necessary to ensure fish health. An improved instream fishery flow regime in the Merced River is also required in conjunction with flow/water-quality improvements on the main stem San Joaquin River to protect the anadromous fish resource (i.e., to attract chinook salmon up the Merced River to spawn, and to discourage them from being drawn to tributaries in the Grasslands area).

Protection of remaining wildlife habitats and populations in the subarea will probably require acquisition and management of some lands by wildlife organizations and/or appropriate financial incentives for private landowners to forgo conversion of wetlands (e.g., through acquisition of perpetual wetlands easements in the western and eastern Grasslands area). The acquisition and development of new wetlands (complete with adequate, firm

supplies of nontoxic freshwater) would likely provide migratory birds and a broad variety of other wetland-dependent wildlife species with additional protection from drainage-water contaminants. Additional, high-quality wetland habitat would be expected to preferentially draw some wildlife away from evaporation ponds, thereby reducing the numbers of individuals exposed to drainage-water contaminants, and/or decreasing exposure frequencies and/or durations. Consequently, the frequencies and/or severity of contaminant-caused biological effects associated with the ponds, and public health risks associated with game birds using the ponds, would be expected to be reduced.

Additional biological monitoring and field and laboratory research are needed to fill in data gaps and determine, for example: (1) What the concentrations of drainage contaminants are in water, sediments, and food-chain organisms in all fish and wildlife habitats in the subarea that are, or have been, exposed to drainage water, (2) whether adverse biological effects are continuing at evaporation ponds studied to date, and/or at ponds which have not yet been studied, and (3) the quantity, quality, and schedule of instream fishery flows needed in this reach of the main stem San Joaquin River to support a viable fishery.

All drainage-contaminated habitats (including Los Banos WA and duck clubs in the northwestern and southwestern Grasslands area) require concerted action to ensure decontamination and restoration. Studies conducted in the western Grasslands area reveal that the provision of nontoxic water supplies to wetlands that have been contaminated by subsurface drainage water is likely to be of great assistance in their decontamination and restoration (USFWS-SLNWR, 1988). In addition, improving the quality (health) of existing wetlands, increasing the frequency of their flooding, and adding to the overall acreage

of wetland habitats would provide wetlands-dependent wildlife with alternative habitat, thereby decreasing their reliance on drainage-contaminated habitats and increasing their protection.

Substitute water supplies for existing wildlife areas in the Grasslands Subarea total 129,000 acre-ft/yr.

The remaining anadromous fish habitat in the upper San Joaquin River would benefit from substantially increased instream freshwater flows, although the exact instream fishery flow requirements for this reach of the river have not yet been determined.

Improvement of wildlife resources in this subarea would occur if: existing public and private wildlife areas were provided with an additional firm, nontoxic, freshwater supply of more than 216,000 acre-ft/yr (equal to the additional water needed to satisfy optimum management objectives for existing lands); and/or 25,000 acres of new wetlands and associated water supplies were provided in the subarea.

Available Technologies Alternative

The available technologies alternative for the Grasslands Subarea for the year 2000 is comprised of three components: (1) Actions to sustain irrigated agriculture, (2) actions to protect public health, and (3) actions to protect and restore fish and wildlife and their habitats. Each component is discussed and presented in the following sections. The State water-quality objectives for surface water are viewed as constraints that would be met simultaneously with accomplishment of these actions, and the technical analyses have taken this into account--limiting actions that do meet the constraints.

<u>Actions to sustain agriculture</u>. Tables 4-4 through 4-6 present options that have been applied to reduce problem-water volumes in water-quality Zones A, B, and C, respectively (Figure 4-G8). From examination and comparison of these tables, the following can be concluded about the agricultural component of the alternative:

- o Source-control options would achieve 47 percent of the problem-water reduction in Zone A and 26 percent in Zone B. Source control is not included for Zone C because drainage water produced here is comparatively free of selenium and sufficiently low in other substances of concern that it is assumed it may be discharged to the San Joaquin River or its tributaries.
- o For Zones A and B, drainage-water reuse options would achieve problem-water reductions of 36 and 38 percent, respectively.
- o Discharge to the San Joaquin River would account for the following reductions of problem water: 17 percent of Zone A, 36 percent of Zone B, and all (100 percent) of Zone C. These reductions are based on projected concentrations of selenium in drainage water and the assimilative capacity of the San Joaquin River.
- o In both Zones A and B, pumping of relatively high-quality ground water from the semiconfined aquifer would be used in conjunction with irrigation of saltbush with drainage water. Pumping of water from the aquifer draws down the water table and allows storage space for deep percolation from the saltbush.
- o An existing evaporation pond (50 acres) would be used in Zone A to dispose of a small volume of problem water. No new evaporation ponds are included in any of the three zones.

Table 4-4

AVAILABLE TECHNOLOGIES ALTERNATIVE
GRASSLANDS SUBAREA - ZONE A

(Estimated volume of problem water to be managed by year 2000 = 53,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	35,000	1,925,000	14,000
A-2, A-3	Improve irrigation management	5	35,000	175,000	7,000
A-9	Manage water table to increase evapotranspiration	30	17,000	510,000	3,400
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	2,600	1,625,000	14,900
D-1	Irrigate saltbush (c)	241	1,000	241,000	3,100
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (d)	154	1,000	154,000	1,400
	Drainage-Water Disposal				
E-1	Discharge to San Joaquin River without dilution	NA	12,000	NA	9,000
E-5	Use existing evaporation ponds (e)	240	50	12,000	200
TOTALS				4,642,000	53,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.
(b) Includes 1,900 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.
(c) Includes 600 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.
(d) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.
(e) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

Table 4-5

AVAILABLE TECHNOLOGIES ALTERNATIVE
GRASSLANDS SUBAREA - ZONE B

(Estimated volume of problem water to be managed by year 2000 = 11,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	3,500	192,500	1,400
A-2, A-3	Improve irrigation management	5	3,500	17,500	700
A-9	Manage water table to increase evapotranspiration	30	3,500	105,000	700
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	600	375,000	3,300
D-1	Irrigate saltbush (c)	241	200	48,200	600
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (d)	154	200	30,800	300
	Drainage-Water Disposal				
E-1	Discharge to San Joaquin River without dilution	NA	5,000	NA	4,000
TOTALS				769,000	11,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 400 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Includes 100 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(d) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

Table 4-6

AVAILABLE TECHNOLOGIES ALTERNATIVE
GRASSLANDS SUBAREA - ZONE C

(Estimated volume of problem water to be managed by year 2000 = 22,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Drainage-Water Disposal				
E-1	Discharge to San Joaquin River without dilution	NA	30,000	NA	22,000
TOTAL					22,000

Costs of the agricultural component are calculated as follows:

1. Average annual cost of source-control options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$2{,}925{,}000}{27{,}200\ \text{AF}} = \$108/\text{AF}$$

2. Average annual cost of combined reuse, disposal, and ground-water options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$2{,}486{,}000}{58{,}800\ \text{AF}} = \$42/\text{AF}$$

3. Average annual cost of the agricultural component:

$$\frac{\text{costs } (\$2{,}925{,}000 + \$2{,}486{,}000)}{\text{volumes } (27{,}200\ \text{AF} + 58{,}800\ \text{AF})} = \frac{\$5{,}411{,}000}{86{,}000\ \text{AF}} = \$63\ \text{AF of problem water}$$

costs (\$63/AF) X drainage factor (0.75 AF/acre) = \$47/acre of contributing land

To summarize, the set of actions to sustain irrigated agriculture in the Grasslands Subarea under this alternative is: (1) Conserve irrigation water through improvements in technology and management, (2) reuse drainage water on eucalyptus trees, (3) drain the eucalyptus trees, (4) reuse the resultant drainage water on saltbush, (5) dispose of the deep percolation from saltbush by either draining or pumping from beneath the saltbush (storing water with high levels of mineral concentrations in bird-safe evaporation ponds or in the upper part of the semiconfined aquifer), and (6) use the San Joaquin River for assimilation of problem water, to the extent that the State water-quality objective of 5 ppb selenium is not exceeded.

Actions to minimize public health risks. General actions that could be continued or undertaken to minimize public health risks in the Grasslands Subarea are listed in the "Public Health Component" section located near the beginning of this chapter. Warning signs would be posted at every public access point along Camp 13 Ditch, Helm Canal, Mud Slough, San Luis Canal, Los Banos WA, and selected private duck clubs.

Actions that would protect, restore, and provide substitute water supplies for fish and wildlife resources. Water quality in the San Joaquin River and west-side tributaries has been and continues to be degraded by discharge of untreated drainage waters. Protection of existing fisheries in the Grasslands Subarea could occur through improvement of water quality and flow through reduction in the discharge of drainage water and/or provision of additional instream freshwater flows. Spawning salmon which are currently being lethally attracted into west-side tributaries in the Grasslands area could be protected through: provision of additional flows in the Merced River each October (these additional instream fishery flow needs total about 20,000 acre-ft); or until such flows are made available, continued operation of the fish trapping station on San Luis Canal (cost about $100,000/yr); and construction and operation of similar facilities on Mud Slough and/or Los Banos Creek (costs are currently unknown).

Protection of existing wildlife resources in the Grasslands Subarea could occur through: (1) Continuation of ongoing efforts by wildlife organizations to acquire and manage or otherwise legally protect remaining unprotected wetlands and other valuable wildlife habitats in the subarea (unprotected wetlands in the subarea [i.e., duck club wetlands that are not covered by conservation easements] currently total approximately 31,000 acres), (2) provision of a firm, nontoxic freshwater supply to all remaining wetlands-wildlife areas (the freshwater supply deficit for the subarea totals more than 216,000 acre-ft/yr), and/or (3) acquisition and development of new wetlands (up to 25,000 acres of additional wetlands complete with adequate, firm supplies of nontoxic freshwater [about 92,500 acre-ft/yr] are needed in the middle and southern San Joaquin Basin to support international waterfowl

population objectives). If combined with hazing programs at the ponds, the provision of adequate, firm, nontoxic freshwater supplies for existing wetlands-wildlife areas and/or the purchase and development of new wetlands would reduce some of the ongoing and anticipated adverse effects upon aquatic birds created by some evaporation ponds in the subarea. Drainage-water evaporation ponds in the valley need to be treated as special cases, because although they are not specifically managed as wildlife habitat, they nonetheless experience considerable use by aquatic birds. Due to contamination of some ponds, they can also be lethal, attractive nuisances. Actions that are currently being taken to address this problem include signing of mutual "monitoring and mitigation agreements" between pond owners and the DFG which require hazing at toxic ponds. Additionally, field testing of various techniques to make the ponds bird-safe or bird-free is occurring at selected ponds but could be greatly expanded. A third set of actions that would further reduce adverse effects at the ponds is the development and management of new wetlands habitat in their vicinity.

As noted earlier, a large number of waterways and a broad expanse of wetlands in the Grasslands Subarea have been contaminated by drainage water. With the exception of evaporation ponds, the decontamination and restoration of healthy fish and wildlife communities could be greatly accelerated through the provision of nontoxic water supplies to these habitats.

Adequate, firm, nontoxic freshwater supplies totaling 129,000 acre-ft/yr are needed to satisfy the substitute water supplies for public and private wildlife areas in the Grasslands Subarea.

The provision of adequate, additional volumes of firm, nontoxic freshwater supplies to wetlands and waterways in the Grasslands Subarea would go a long way toward addressing drainage-related and other fish and wildlife resource problems. Provision of such waters could: (1) Help protect existing fish populations and existing and potentially increased wildlife populations, (2) facilitate decontamination of wetland and aquatic habitats, and (3) assist in satisfying substitute water supply needs. The SJVDP has estimated that approximately 200,000 acre-ft/yr of irrigation water currently used on the west side and southern end of the San Joaquin Valley could be conserved through on-farm water conservation, improved drainage management, drainage water reuse, and ground-water pumping. Under the available technologies alternative, some of that conserved water would be reallocated: for instream flows in the Merced River during October to facilitate upstream migration of spawning salmon (20,000 acre-ft/yr); and to existing wetlands-wildlife areas in the subarea (129,000 acre-ft/yr), used for fall-winter flooding, and released into the San Joaquin River during the spring to assist downstream migration of juvenile salmon.

An additional action would facilitate delivery of freshwater to wetlands and decontamination of wetlands and most waterways and associated riparian habitats in the Grasslands Subarea. That action is construction and operation of the Zahm-Sansoni-Nelson plan (or a recently proposed variation to that plan) and involves modification of water delivery and drainage systems to: (1) Separate freshwater from drainage water, (2) free up interior canals, ditches, creeks, and sloughs to carry/deliver freshwater to wetlands throughout the western Grasslands area, and (3) convey drainage water through the San Luis Drain to the San Joaquin River via Mud Slough or Newman Wasteway (including a 6-mile intertie to the wasteway).

WESTLANDS SUBAREA

The Westlands Subarea (Figure 4-W1) includes about 1,203 square miles (770,000 acres) of predominantly rural land in western Fresno and Kings Counties. The subarea is about 70 miles long and 15 miles wide and extends from the community of Mendota in the north to Kettleman City in the south. The eastern boundary of the subarea follows generally the topographic center (low point) of the San Joaquin Valley; the western boundary lies along the foothills of the Coast Range. The major land use is irrigated agriculture.

The subarea includes all lands in the Westlands Water District, the James Irrigation District, Tranquillity Irrigation District, and Fresno Slough Water District. The subarea is unique hydrologically because it drains into both the San Joaquin and Tulare Basins.

The subarea is sparsely settled, with an estimated 1989 population of about 11,000 residing primarily in ten small communities.

Although Pleasant Valley Irrigation District and the community of Coalinga are located within the Westlands Subarea, the principal ground-water aquifer is isolated hydraulically from the rest of the subarea and does not exhibit shallow ground-water quality problems. Therefore, these areas are not addressed in this report.

The lands identified as having potential drainage problems are located in the easterly part of the subarea, usually extending from the middle of alluvial fans downslope to the valley floor.

Irrigated Agriculture

Water supply. Irrigation water supplies in the Westlands Subarea consist of imports from the Delta, diversions from the San Joaquin River, and local ground water. The major source of irrigation water since 1968 has been CVP supplies diverted through the Delta-Mendota and San Luis Canals. The average

annual firm irrigation water supply is about 1,580,000 acre-feet: 1,420,000 acre-feet from the canals and 160,000 acre-feet of local ground water.

There are no organized drainage districts in the subarea, although Westlands Water District has the authority to manage and has managed both water deliveries and drainage flows.

From 1981 to July 1986, 7,000 to 8,000 acre-feet/year of drainage water was collected from parts of a 42,000-acre tract of land in Westlands Water District and discharged into the San Luis Drain, which conveyed the drainage to Kesterson Reservoir for evaporation and seepage. Originally this drainage water was considered a water supply because it supported a wetland habitat in the Kesterson area. Subsequently the drainage water was shown to include contaminants, which caused severe adverse biological effects upon wildlife using the reservoir. Following cessation of discharge to the San Luis Drain and Kesterson Reservoir, Westlands Water District began to recycle, and continues to recycle, subsurface drainage into its agricultural water supply.

The quality of water delivered to the subarea from the Delta ranges from 250 to 450 ppm TDS. Ground-water supplies are generally much more saline than Delta water and therefore are either blended with the imported water supply or special management practices are applied in their use.

Drainage-related water quality. Figure 4-W2 shows shallow ground water at depths of 0-5, 5-10, and 10-20 feet below the land surface in 1987. The shallow ground water contains a wide range of concentrations of salt, boron, selenium, molybdenum, and arsenic. The areal distribution of these dissolved constituents is shown in Figures 4-W3, 4-W4, 4-W5, 4-W6, and 4-W7.

FIGURE 4-W1

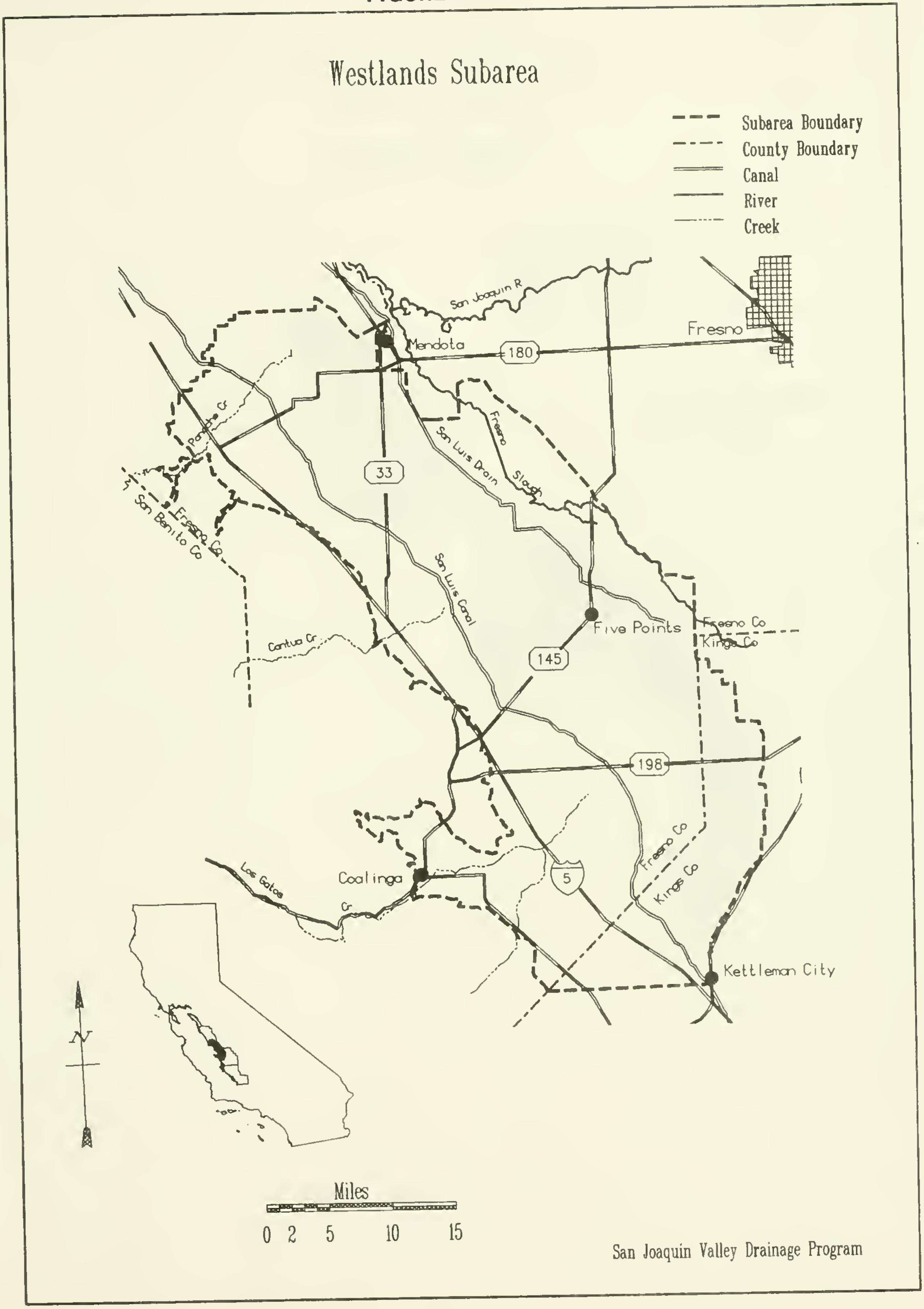

Westlands Subarea
Subarea Boundary
County Boundary
Canal
River
Creek
San Joaquin R
Fresno
Mendota
180
Fresno
San Luis Drain
Slough
33
Panoche Cr
Fresno Co
San Benito Co
San Luis Canal
Cantua Cr
Five Points
Fresno Co
Kings Co
145
198
Fresno Co
Kings Co
Los Gatos
Cr
Coalinga
5
Kettleman City
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-W2

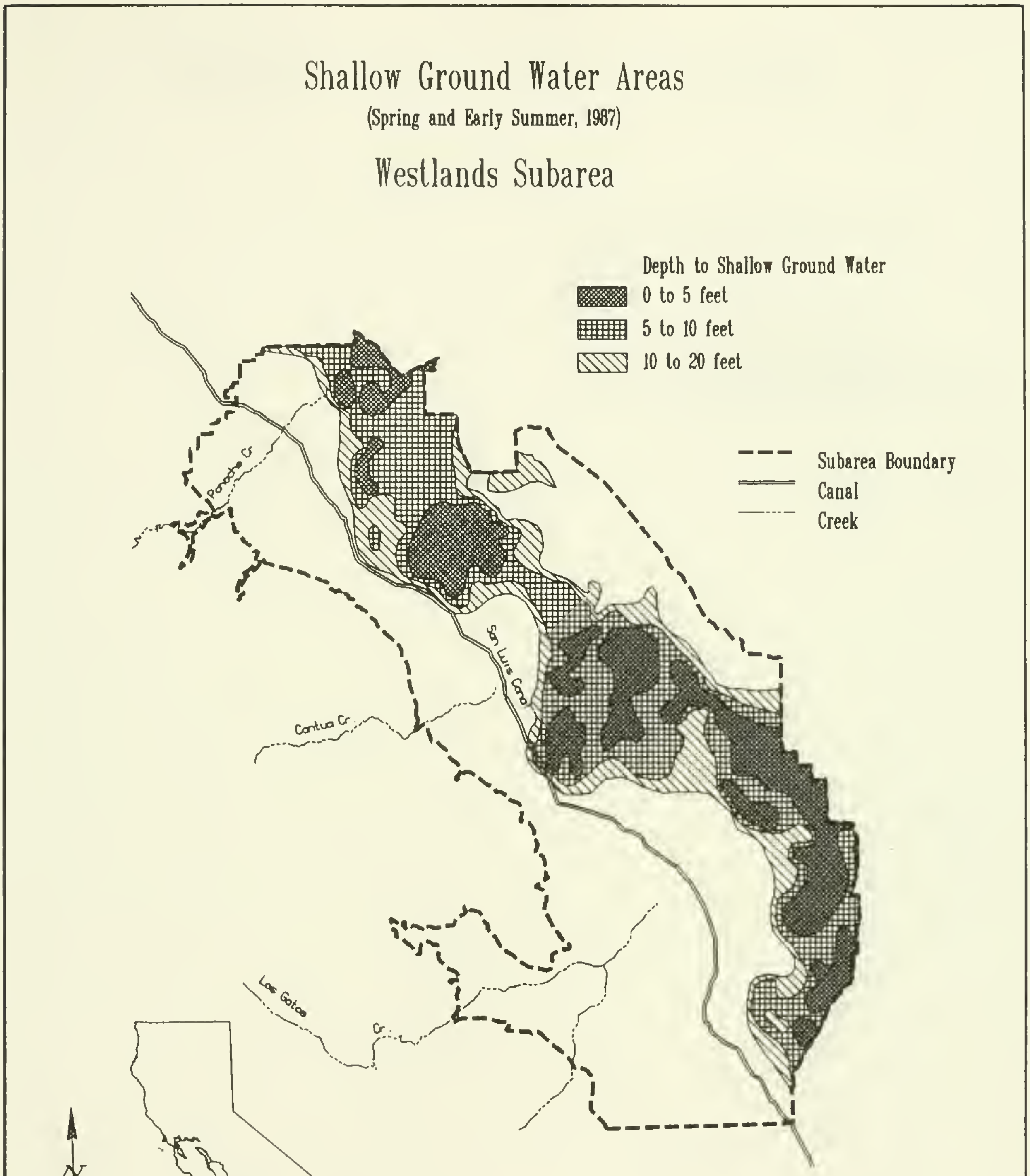
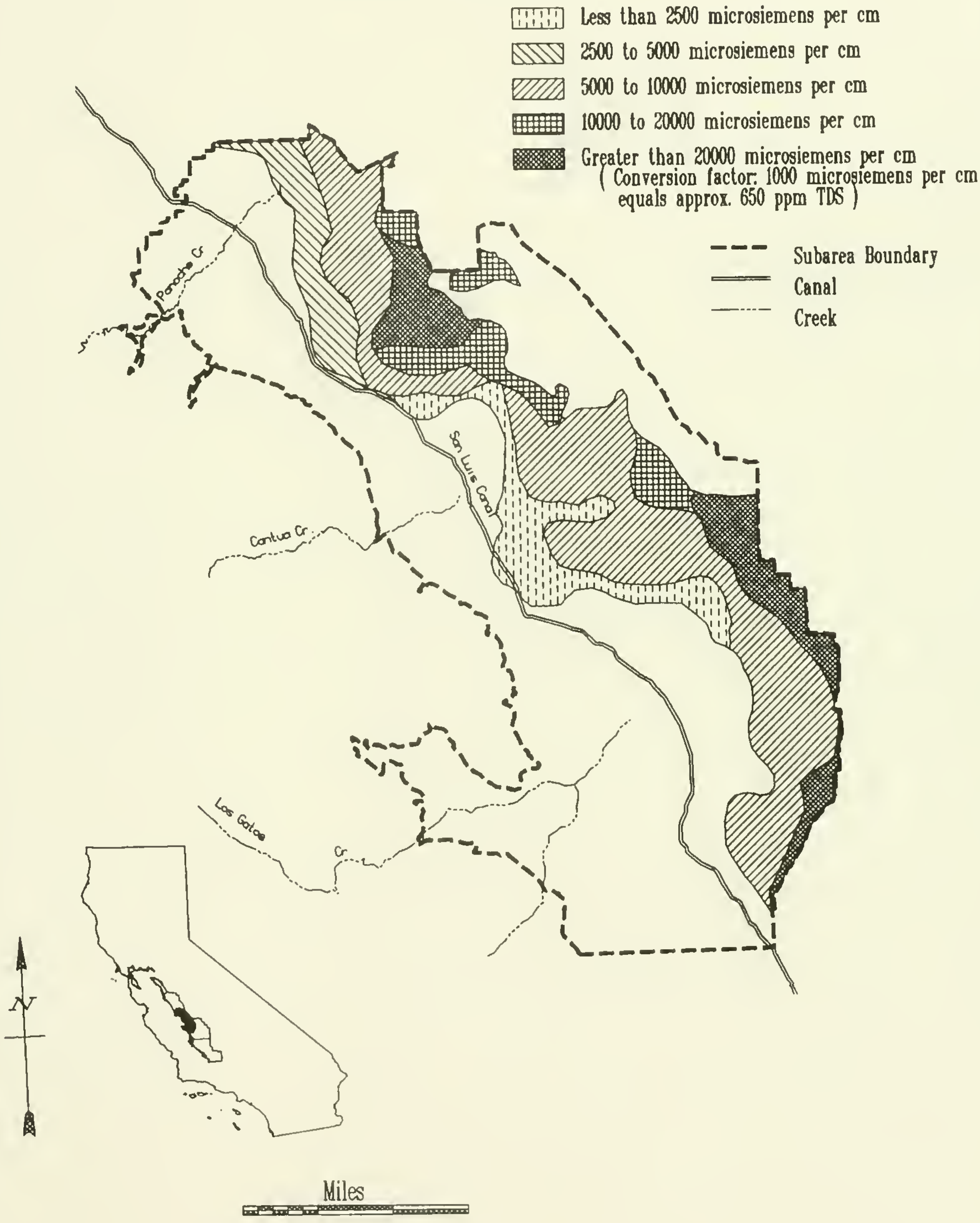

Shallow Ground Water Areas
(Spring and Early Summer, 1987)
Westlands Subarea
Depth to Shallow Ground Water
0 to 5 feet
5 to 10 feet
10 to 20 feet
Subarea Boundary
Canal
Creek
Panoche Cr.
San Luis Canal
Cantua Cr.
Los Gatos Cr.
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-W3

Electrical Conductivity of Shallow Ground Water

(Sampled between 1984 and 1987)

Westlands Subarea



San Joaquin Valley Drainage Program

FIGURE 4-W4

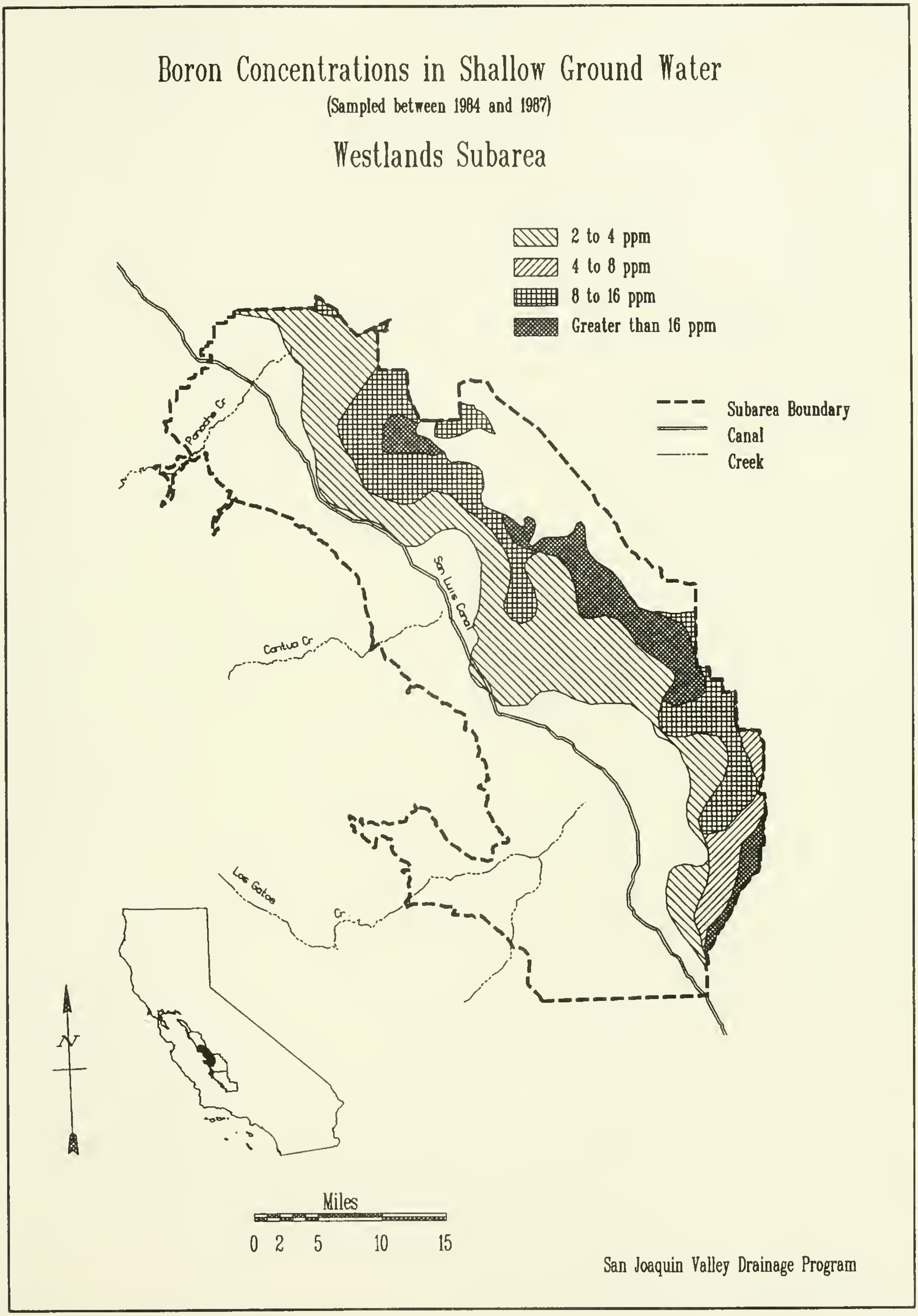

Boron Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Westlands Subarea
2 to 4 ppm
4 to 8 ppm
8 to 16 ppm
Greater than 16 ppm
Subarea Boundary
Canal
Creek
Panoche Cr
San Luis Canal
Cantua Cr
Los Gatos Cr
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-W5

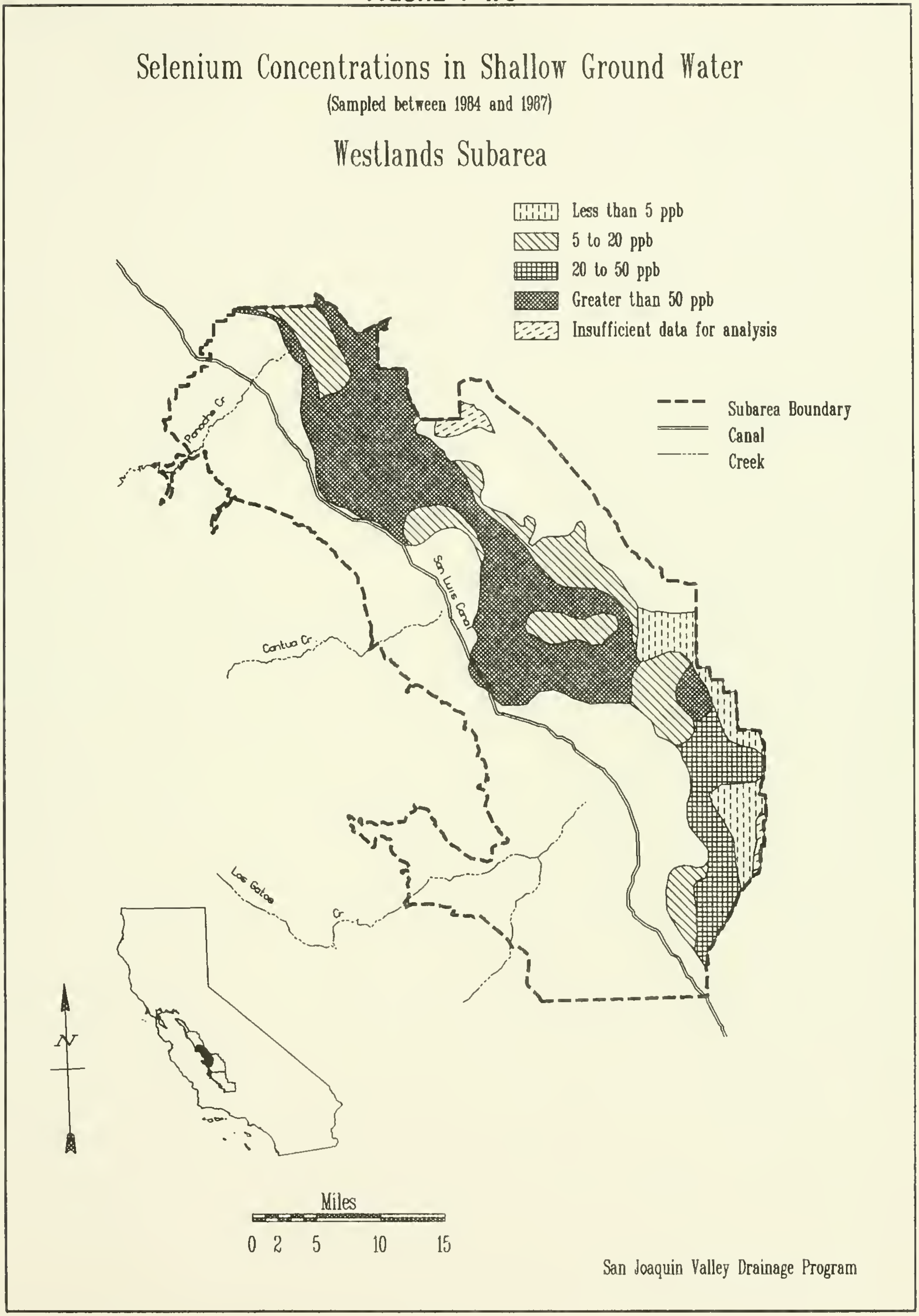
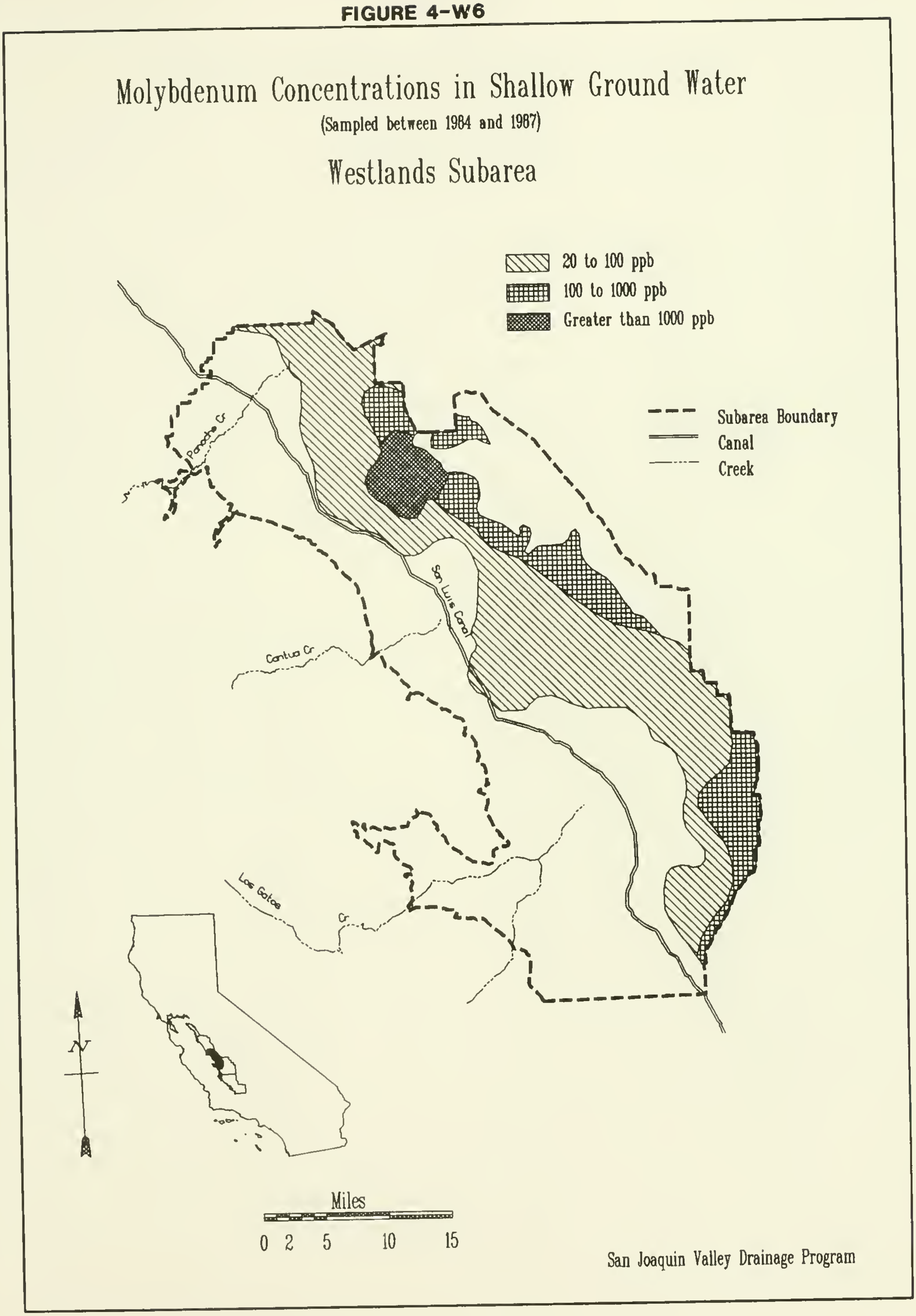
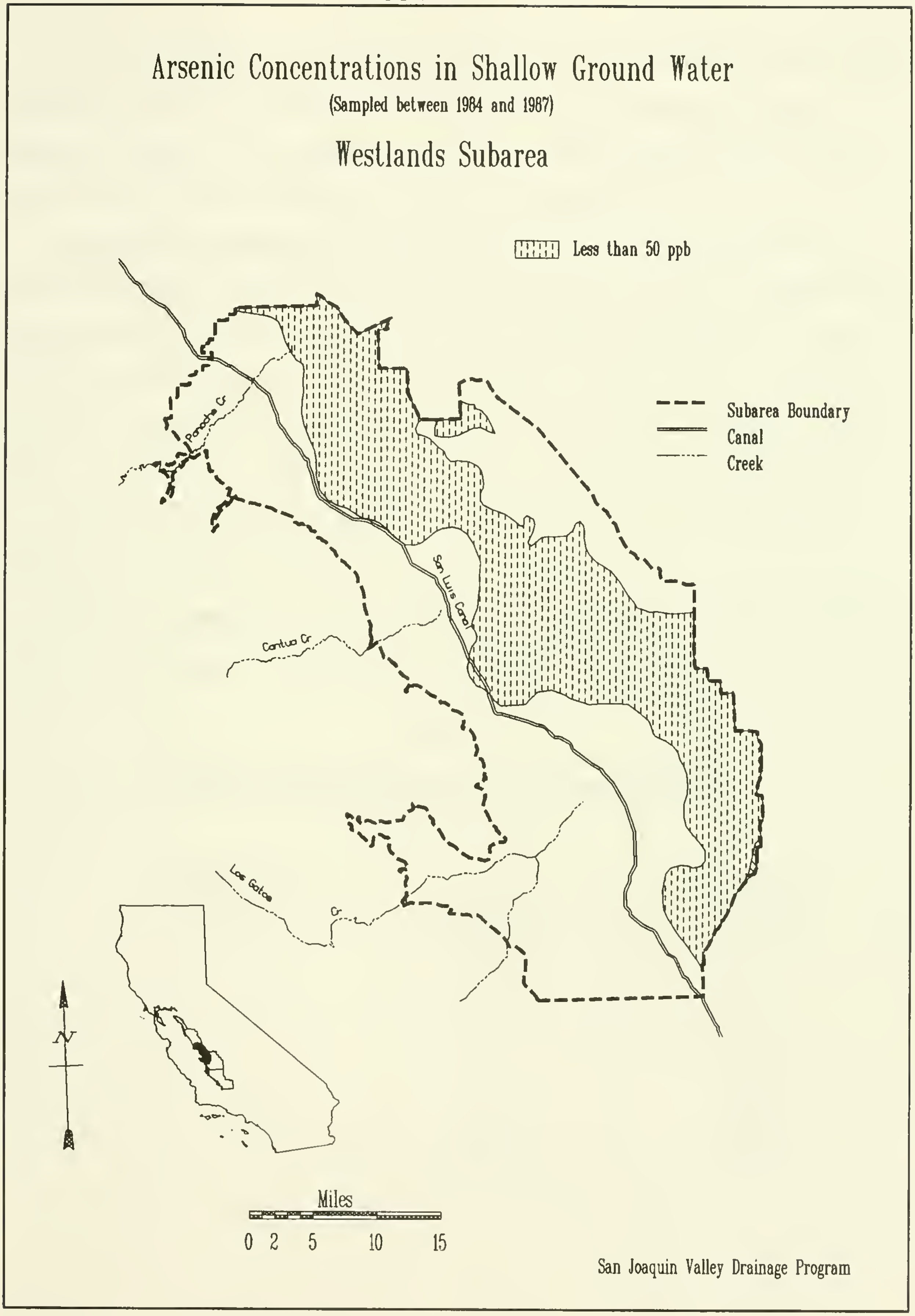

Selenium Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Westlands Subarea
Less than 5 ppb
5 to 20 ppb
20 to 50 ppb
Greater than 50 ppb
Insufficient data for analysis
Subarea Boundary
Canal
Creek
Panoche Cr
San Luis Canal
Cantua Cr.
Los Gatos Cr.
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-W6



Molybdenum Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Westlands Subarea
20 to 100 ppb
100 to 1000 ppb
Greater than 1000 ppb
Subarea Boundary
Canal
Creek
Panoche Cr
San Luis Canal
Cantua Cr
Los Gatos Cr
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-W7


Arsenic Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Westlands Subarea
Less than 50 ppb
Subarea Boundary
Canal
Creek
Panoche Cr
San Luis Canal
Cantua Cr
Los Gatos Cr
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

Only small amounts of subsurface drainage from this subarea are currently discharged to public surface-water bodies. However, about 150 acres of evaporation ponds receive and concentrate drainage, in some cases to levels declared toxic under California's Toxic Pits Cleanup Act.

Agricultural drainage problem. Approximately 104,000 acres of the agricultural land in this subarea (about 15 percent of the total subarea) had ground-water levels within 5 feet of the land surface during part of 1987. In 1977, only 32,000 acres fell into this category, and the area is expected to increase to 169,000 acres by the year 2000. Salt load in the shallow ground water is accumulating in the subarea at the rate of about 600,000 tons/year.

Generally, the high water-table conditions impair water quality, crop selection, and crop productivity.

Annual problem-water volumes have been estimated for each water-quality zone in this subarea. (See Table 4-7 and Figure 4-W8.)

Table 4-7

ANNUAL PROBLEM-WATER VOLUME - WESTLANDS SUBAREA
(For Year 2000)

Water-Quality Zone	Drained Area (acres)	Problem-Water Volume (acre-ft)
A	29,000	23,000
B	20,000	16,000
C	47,000	36,000
D	12,000	9,000
TOTAL	108,000	84,000

Planning objectives for agriculture. For planning purposes, it is assumed that the amount of land drained will increase from about 5,000 acres in 1987 to about 108,000 acres by the year 2000, as growers act to manage shallow ground water.

The agricultural objective for the Westlands Subarea is to eliminate or manage the problem-water volume shown in Table 4-7 by a combination of source-control measures and other appropriate alternatives so the drainage water is not a problem to agriculture or to other public values (e.g., water quality, public health, and fish and wildlife).

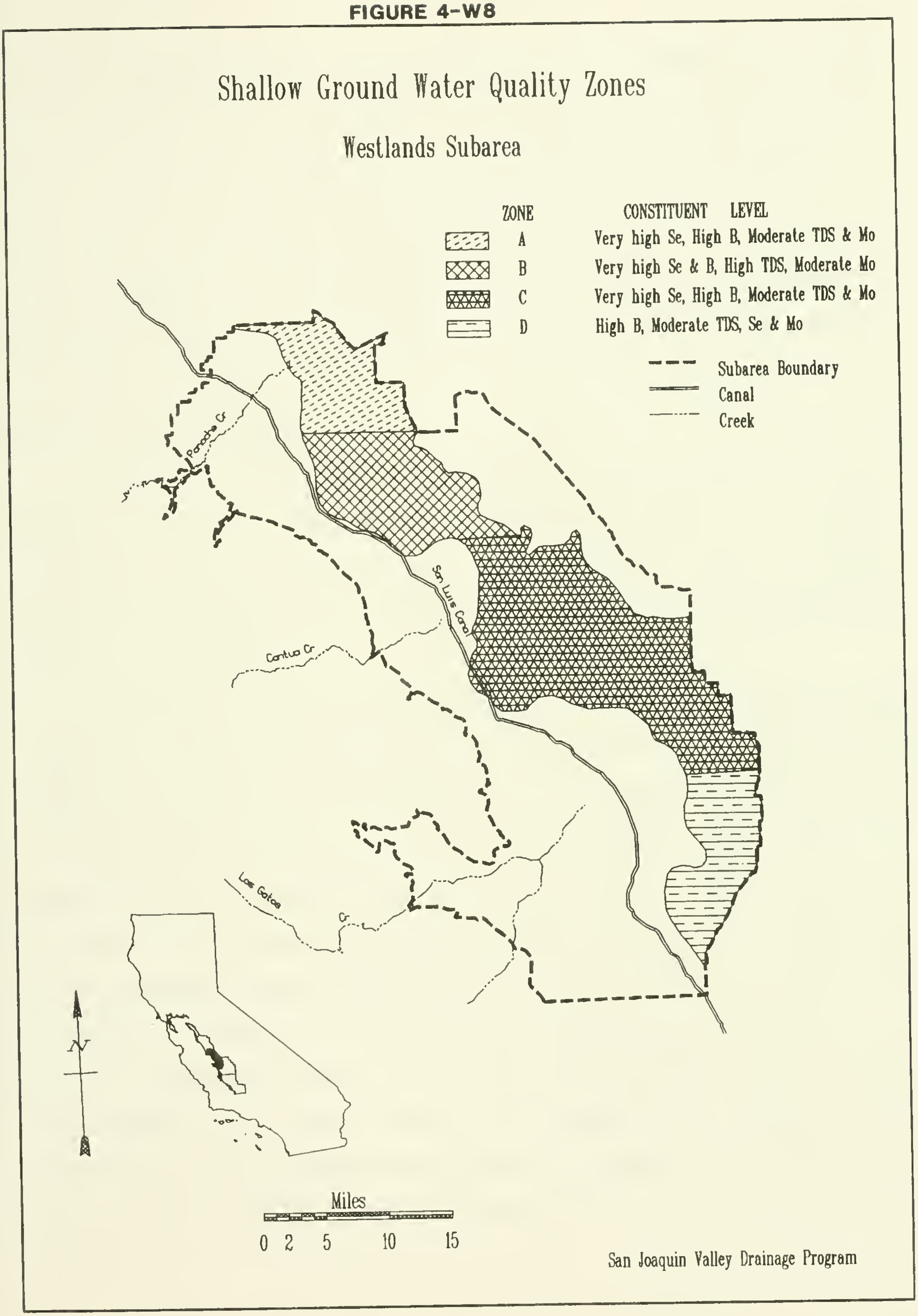
Public Health

Conditions. Part of the San Luis Drain (in the eastern portion of the Westlands Subarea) is posted with warnings of health risks from selenium contamination to forbid trespassing, fishing, or hunting along the drain. Crops and livestock in the subarea have been sampled for unsafe levels of selenium; unsafe levels have not been found.

There are three evaporation ponds in the Westlands Subarea. There are limited biological residue data from two of these ponds (Britz Deavenport Five Points and Sumner Peck). Samples of widgeongrass collected from both ponds in June and August 1987 exceeded the DHS selenium guidance level (S. A. Ford and D. K. Hoffman-Floerke, DWR, Sacramento and Fresno, CA [unpublished data]). Widgeongrass is an aquatic plant identified as a species collected by foragers in the San Joaquin Basin (M. Campbell and L. C. Christensen, UCD, Davis, CA [unpublished data]).

Objectives. The public health objectives for this subarea are to: (1) Restore (decontaminate) any habitat that would likely prove harmful to humans, (2) conduct both biological and chemical monitoring of existing

FIGURE 4-W8


Shallow Ground Water Quality Zones
Westlands Subarea
ZONE
CONSTITUENT LEVEL
A
Very high Se, High B, Moderate TDS & Mo
B
Very high Se & B, High TDS, Moderate Mo
C
Very high Se, High B, Moderate TDS & Mo
D
High B, Moderate TDS, Se & Mo
Subarea Boundary
Canal
Creek
Panoche Cr
San Luis Canal
Cantua Cr
Los Gatos
Cr
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

habitats and any new habitats that might be created in attempts to solve the drainage problem or manage drainage-water discharges (e.g., new evaporation ponds), and (3) monitor potential human exposure sources for additional substances of concern and continue to monitor selenium in local produce to assure safe concentrations. The objective of monitoring is to compare existing selenium levels with background levels and public health action thresholds, creating basic information for risk determination, and warnings and closures--as appropriate.

Fish and Wildlife Resources

Description. The Westlands Subarea contains 640,000 acres of irrigable farmland. There are no lands within this subarea that are primarily managed for fish or wildlife resources or associated public uses. There is riparian vegetation along Fresno Slough, James Bypass, and some of the stream channels in the west-side foothills.

Other than irrigation canals and drainage ditches, the principal flowing water feature in the subarea is a portion of Fresno Slough. Fresno Slough supports an assortment of warm-water fish species including striped bass.

Newly created habitats in the subarea include three drainage-water evaporation ponds developed during the past 7 years (covering a total of 525 acres, about 7 percent of all the evaporation pond acreage in the valley) and an expanding acreage of agroforestry plantations (many planted in the last 2-4 years). The evaporation ponds are heavily used by aquatic birds for wintering and breeding habitat (Barnum, 1989; Hoffman-Floerke, 1985; Schroeder et al., 1988; Tribbey, 1988; Tribbey and Beckingham, 1986). Studies conducted by CSU, Fresno, for the SJVDP have revealed that agroforestry plantations provide perching, nesting, and burrowing habitat for a variety of birds and mammals.

Problems. Contamination field studies have documented elevated concentrations of selenium (an indicator of contamination by subsurface drainage water) in water (greater than 5 ppb) and/or sediments (greater than 0.5 ppm, dry weight) collected from all three evaporation ponds in the Westlands Subarea including: Britz Deavenport Five Points, Carlton Duty, and Sumner Peck (Westcot el al., 1988a). Food-chain organisms have been collected from two of the three evaporation ponds in the subarea and chemically analyzed for selenium (no biological residue data for selenium are available for the Carlton Duty evaporation pond). Concentrations of selenium toxic to mallards (equal to or greater than 7 ppm, dry weight) have been found in food-chain organisms collected from both of those ponds (D. A. Barnum and D. S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; S. A. Ford and D. K. Hoffman-Floerke, DWR, Sacramento and Fresno, CA [unpublished data]; T. Heyne, CSUF and M. Kie, DFG, Fresno, CA [unpublished data]; and White et al., 1987). Studies of reproduction and survival of aquatic birds have been conducted at one of the three ponds (Sumner Peck). Significantly elevated frequencies of adverse biological effects (that are believed to be contaminant-related) have been documented in breeding aquatic birds at those ponds (Ohlendorf, 1988; Skorupa, 1989; Skorupa and Ohlendorf, 1989; and Skorupa and Ohlendorf, 1988).

There appears to be no surface discharge of agricultural drainage water into Fresno Slough or biological residue data for drainage-water contaminants from the slough.

It is currently unknown whether agroforestry plantations in the subarea are contaminated by drainage-water substances of concern such that they pose a contaminant threat to wildlife using the sites.

Wildlife agencies and interests have determined that the Tulare Basin (including the Westlands, Tulare, and Kern Subareas) is 5,000 acres short of the wetland habitat needed to support international waterfowl population objectives (USFWS, 1987; USFWS and Canadian Wildlife Service, 1986).

Objectives. Protection of remaining wildlife habitats (e.g., remnant riparian vegetation along west-side tributaries and Fresno Slough) and populations in the subarea may require acquisition and management of some lands by wildlife organizations and/or appropriate financial incentives for private landowners to forgo conversion of these remaining habitats. The acquisition and development of new wetlands (complete with adequate, firm supplies of nontoxic freshwater) would likely provide migratory birds and a broad variety of other wetland-dependent wildlife species with further protection from drainage-water contaminants. Additional, high-quality wetland habitat would be expected to preferentially draw some wildlife away from evaporation ponds, thereby reducing the numbers of individuals exposed to drainage-water contaminants and/or decreasing exposure frequencies and/or durations. Consequently, the frequencies and/or severity of contaminant-caused biological effects associated with the ponds and public health risks associated with game birds using the ponds would be expected to be reduced.

Additional biological monitoring and field and laboratory research are needed to fill in data gaps and determine, for example: (1) What the concentrations of drainage contaminants are in water, sediments, and food-chain organisms in all fish and wildlife habitats in the subarea that are or have been exposed to drainage water, (2) whether adverse biological effects are continuing at evaporation ponds studied to date, and/or at ponds which have not yet been studied, (3) whether newly established agroforestry

plantations pose drainage-related contaminant threats to wildlife using the sites, and (4) the quantity, quality, and schedule of instream fishery flows needed in Fresno Slough to support a viable fishery.

Concerted action is needed to ensure that those drainage-contaminated evaporation ponds in the subarea (at which significantly elevated frequencies of adverse biological effects have been documented) are managed to keep wildlife out, operated in a wildlife-safe manner, or are decontaminated and closed. No other habitat decontamination and restoration needs have been identified to date in the subarea.

Improvement of wildlife resources in the Westlands Subarea would occur if 5,000 acres of new wetlands and associated water supplies were provided. Instream fishery flow needs for Fresno Slough are unknown.

Available Technologies Alternative

The available technologies alternative for the Westlands Subarea for the year 2000 is comprised of three components: (1) Actions to sustain irrigated agriculture, (2) actions to protect public health, and (3) actions to protect and restore fish and wildlife and their habitats. Each component is discussed and presented in the following sections. The State water-quality objectives for surface water are viewed as constraints that would be met simultaneously with accomplishment of these actions, and the technical analyses have taken this into account--limiting actions that do meet the constraints.

Actions to sustain agriculture. Tables 4-8 through 4-11 present options that have been applied to reduce problem-water volumes within water-quality Zones A, B, C, and D, respectively (Figure 4-W8). From examination and comparison of these tables, the following can be concluded about the agricultural component of the alternative:

Table 4-8

AVAILABLE TECHNOLOGIES ALTERNATIVE
WESTLANDS SUBAREA - ZONE A

(Estimated volume of problem water to be managed by year 2000 = 23,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	15,000	825,000	6,000
A-2, A-3	Improve irrigation management	5	15,000	75,000	3,000
A-9	Manage water table to increase evapotranspiration	30	7,500	225,000	1,500
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	1,700	1,062,500	9,600
D-1	Irrigate saltbush (c)	241	600	144,600	1,900
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (d)	154	600	92,400	1,000
	TOTALS			2,424,500	23,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.
(b) Includes 1,200 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.
(c) Includes 400 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.
(d) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

Table 4-9

AVAILABLE TECHNOLOGIES ALTERNATIVE
WESTLANDS SUBAREA - ZONE B

(Estimated volume of problem water to be managed by year 2000 = 16,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	10,000	550,000	4,000
A-2, A-3	Improve irrigation management	5	10,000	50,000	2,000
A-9	Manage water table to increase evapotranspiration	30	5,000	150,000	1,000
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees	625	0	0	0
D-1	Irrigate saltbush (b)	241	1,900	457,900	6,300
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (c)	154	1,900	292,600	2,700
	TOTALS			1,500,500	16,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 1,500 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

Table 4-10

AVAILABLE TECHNOLOGIES ALTERNATIVE
WESTLANDS SUBAREA - ZONE C

(Estimated volume of problem water to be managed by year 2000 = 36,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	23,000	1,265,000	9,200
A-2, A-3	Improve irrigation management	5	23,000	115,000	4,600
A-9	Manage water table to increase evapotranspiration	30	12,000	360,000	2,400
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	2,600	1,625,000	15,200
D-1	Irrigate saltbush (c)	241	1,000	241,000	3,300
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (d)	154	1,000	154,000	1,300
TOTALS				3,760,000	36,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 2,000 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Includes 600 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(d) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

Table 4-11

AVAILABLE TECHNOLOGIES ALTERNATIVE
WESTLANDS SUBAREA - ZONE D

(Estimated volume of problem water to be managed by year 2000 = 9,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	6,000	330,000	2,400
A-2, A-3	Improve irrigation management	5	6,000	30,000	1,200
A-9	Manage water table to increase evapotranspiration	30	3,000	90,000	600
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	600	375,000	3,400
D-1	Irrigate saltbush (c)	318	200	63,600	700
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (d)	154	200	30,800	300
	Drainage-Water Disposal				
E-5	Use existing evaporation ponds (e)	240	150	36,000	400
	TOTALS			955,400	9,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 400 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Includes 200 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(d) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

(e) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

- Source-control options would reduce the problem-water volume by 44 to 47 percent in each zone.
- Drainage-water reuse options employed in each zone would reduce problem-water volumes by 53 to 56 percent.
- Ground-water management options would be used in each zone in conjunction with reuse of drainage water on saltbush.
- An existing evaporation pond in Zone D (150 acres) would be used to dispose of a small volume of water; unit costs per acre of pond built would be high because of the high concentrations of selenium in drainage water.

Costs of the agricultural component are calculated as follows:

1. Average annual cost of source-control options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$4{,}065{,}000}{37{,}900\ \text{AF}} = \$107/\text{AF}$$

2. Average annual cost of combined reuse, disposal, and ground-water options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$4{,}575{,}400}{46{,}100\ \text{AF}} = \$99/\text{AF}$$

3. Average annual cost of the agricultural component:

$$\frac{\text{costs } (\$4{,}065{,}000 + \$4{,}575{,}400)}{\text{volumes } (37{,}900\ \text{AF} + 46{,}100\ \text{AF})} = \frac{\$8{,}640{,}400}{84{,}000\ \text{AF}} = \$103/\text{AF of problem water}$$

$$\text{costs } (\$103/\text{AF}) \times \text{drainage factor } (0.75\ \text{AF/acre}) = \$77/\text{acre of contributing land}$$

To summarize, the set of actions to sustain irrigated agriculture in the Westlands Subarea under this alternative is: (1) Conserve irrigation water through improvements in technology and management, (2) reuse drainage water on eucalyptus trees, (3) drain the eucalyptus trees, (4) reuse the resultant drainage water on saltbush, and (5) dispose of the deep percolation from saltbush by either draining or pumping from beneath the salt bush (storing

water with high levels of mineral concentrations in bird-safe evaporation ponds or in the upper part of the semiconfined aquifer).

Actions to minimize public health risks. General actions that could be continued or undertaken to minimize public health risks in this subarea are listed in the "Public Health Component" section located near the beginning of this chapter.

Actions that would protect, restore, and provide substitute water supplies for fish and wildlife resources. Protection of existing wildlife resources in the Westlands Subarea could occur through: protection of remaining, unprotected riparian vegetation along west-side tributaries and Fresno Slough through acquisition and management by wildlife organizations or by use of other legal protections; and/or the acquisition, development, and management of new wetlands (up to 5,000 acres of additional wetlands complete with adequate, firm supplies of nontoxic freshwater [about 20,000 acre-ft/yr] are needed in the Tulare Basin [Westlands, Tulare, and Kern Subareas] to support international waterfowl population objectives). If combined with hazing programs at the ponds, the purchase and development of new wetlands would reduce some of the ongoing and anticipated adverse effects upon aquatic birds created by some evaporation ponds in the subarea. Drainage-water evaporation ponds in the valley need to be treated as special cases, because although they are not specifically managed as wildlife habitat, they nonetheless experience considerable use by aquatic birds. Due to contamination of some ponds, they can also be lethal, attractive nuisances. Actions that are currently being taken to address this problem include signing of mutual "monitoring and mitigation agreements" between pond owners and the DFG which require hazing at toxic ponds. Additionally, field testing of various techniques to make the ponds bird-safe or bird-free is occurring at

selected ponds but could be greatly expanded. A third set of actions that would further reduce adverse effects at the ponds is the development and management of new wetlands habitat in their vicinity.

TULARE SUBAREA

The Tulare Subarea (Figure 4-T1) includes about 1,380 square miles (883,000 acres) of predominantly rural land in Kings and western Tulare Counties. The subarea is approximately 50 miles long (north to south) and 35 miles wide (east to west). The northern boundary of the subarea is the southern boundary of Westlands Water District; the eastern boundary generally follows the flatland of the eastern shore of Tulare Lakebed; the southern boundary is the Kern County line; and the western boundary lies along the base of the Coast Range foothills. The major land use is irrigated agriculture.

The subarea includes the communities of Corcoran, Lemoore, and Hanford. The estimated 1989 population of the subarea is 32,500, with growth at almost 3 percent per year.

The lands identified as having potential drainage problems are located primarily in parts of the bed (now dry) of ancestral Tulare Lake--particularly along its western and southern margin.

Irrigated Agriculture

Water supply. Irrigation water supplies in the Tulare Subarea consist of Delta imports; diversions from east-side rivers such as the Kings, Kaweah, and Tule; San Joaquin River water delivered through the Friant-Kern Canal; and local ground water.

Historically, the primary water supply for irrigation was ground water and the Kings River. Supplemental water supplies have been provided through the Friant-Kern Canal since the early 1950's and from the California Aqueduct

since the late 1960's. The annual firm irrigation water supply from the Delta is about 170,000 acre-feet. An additional 820,000 acre-feet/year is provided by ground-water pumping and diversions from east-side rivers and the Friant-Kern Canal.

Nineteen water/irrigation districts are located in the Tulare Subarea. Collectively, these districts receive an average of about 600,000 acre-feet of surface water annually from the Federal and State projects and from direct diversions from surface streams. Growers in the districts and in unincorporated areas pump an additional 390,000 acre-feet of ground water.

The quality of water delivered from the Delta ranges from 250 to 450 ppm salt (TDS). The water supply received from the east-side rivers and Friant-Kern Canal is of even higher quality. Ground-water supplies are moderately to highly saline. Ground water is usually blended with surface-water supplies or used for salt-tolerant crops.

Drainage-related water quality. Figure 4-T2 shows shallow ground water in the subarea at depths of 0-5, 5-10, and 10-20 feet below the land surface in 1987. The shallow ground water contains a wide range of concentrations of salt, boron, selenium, molybdenum, and arsenic. The areal distribution of these dissolved constituents in 1987 is shown in Figures 4-T3, 4-T4, 4-T5, 4-T6 and 4-T7, respectively.

Most of the drainage water produced in the Tulare Subarea is disposed of in 16 evaporation ponds that cover about 5,900 acres.

Agricultural drainage problem. Approximately 320,000 acres of agricultural land in this subarea has ground-water levels within 5 feet of the land surface during part of the year. In 1977, there were 158,000 acres in this category; the forecast for the year 2000 is 366,000 acres.

FIGURE 4-T1

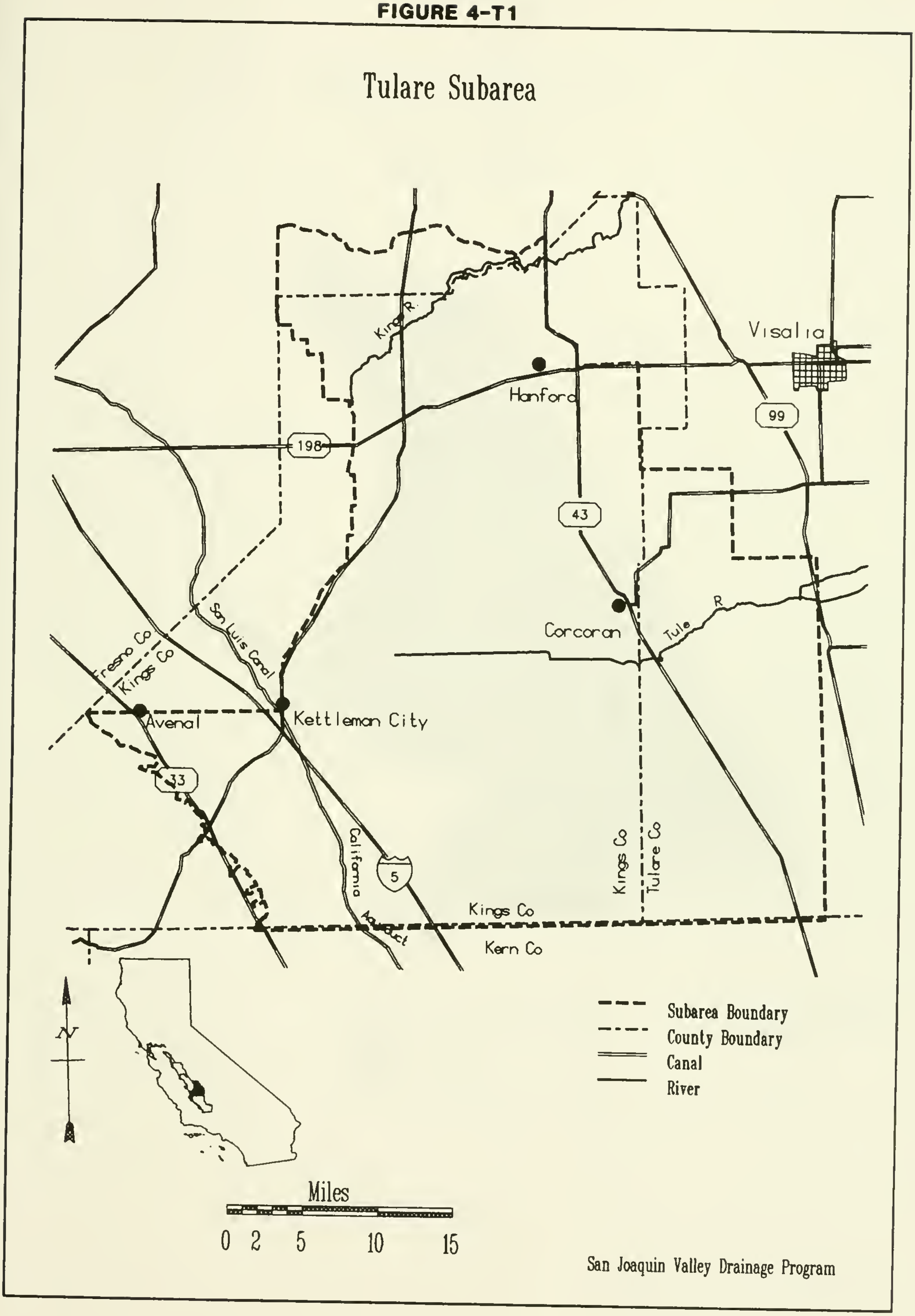

Tulare Subarea
Kings R.
Visalia
Hanford
198
99
43
San Luis Canal
Corcoran
Tule R
Fresno Co
Kings Co
Avenal
Kettleman City
33
California Aqueduct
5
Kings Co
Tulare Co
Kings Co
Kern Co
N
Subarea Boundary
County Boundary
Canal
River
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-T2

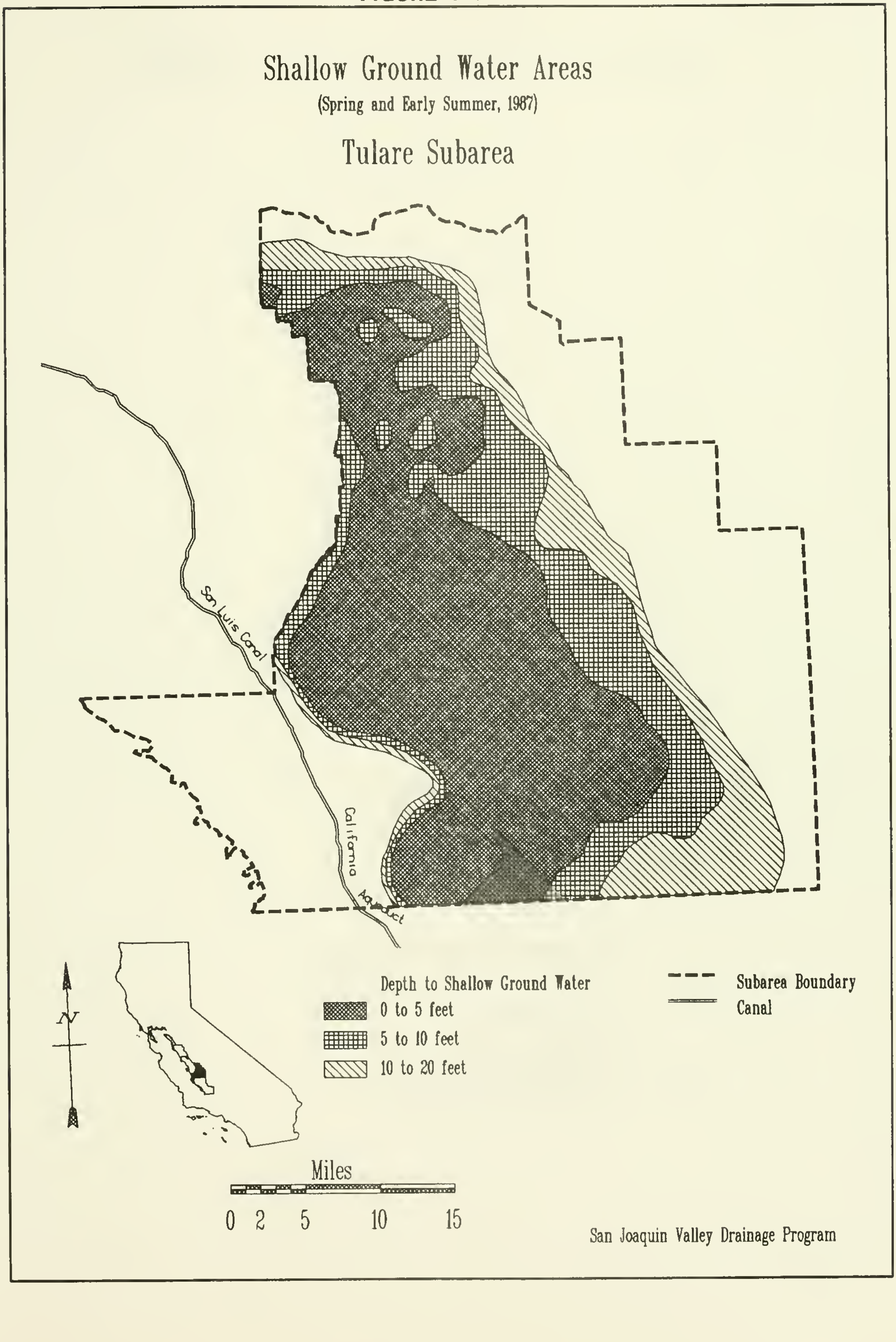

Shallow Ground Water Areas
(Spring and Early Summer, 1987)
Tulare Subarea
San Luis Canal
California Aqueduct
N
Depth to Shallow Ground Water
0 to 5 feet
5 to 10 feet
10 to 20 feet
Subarea Boundary
Canal
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-T3

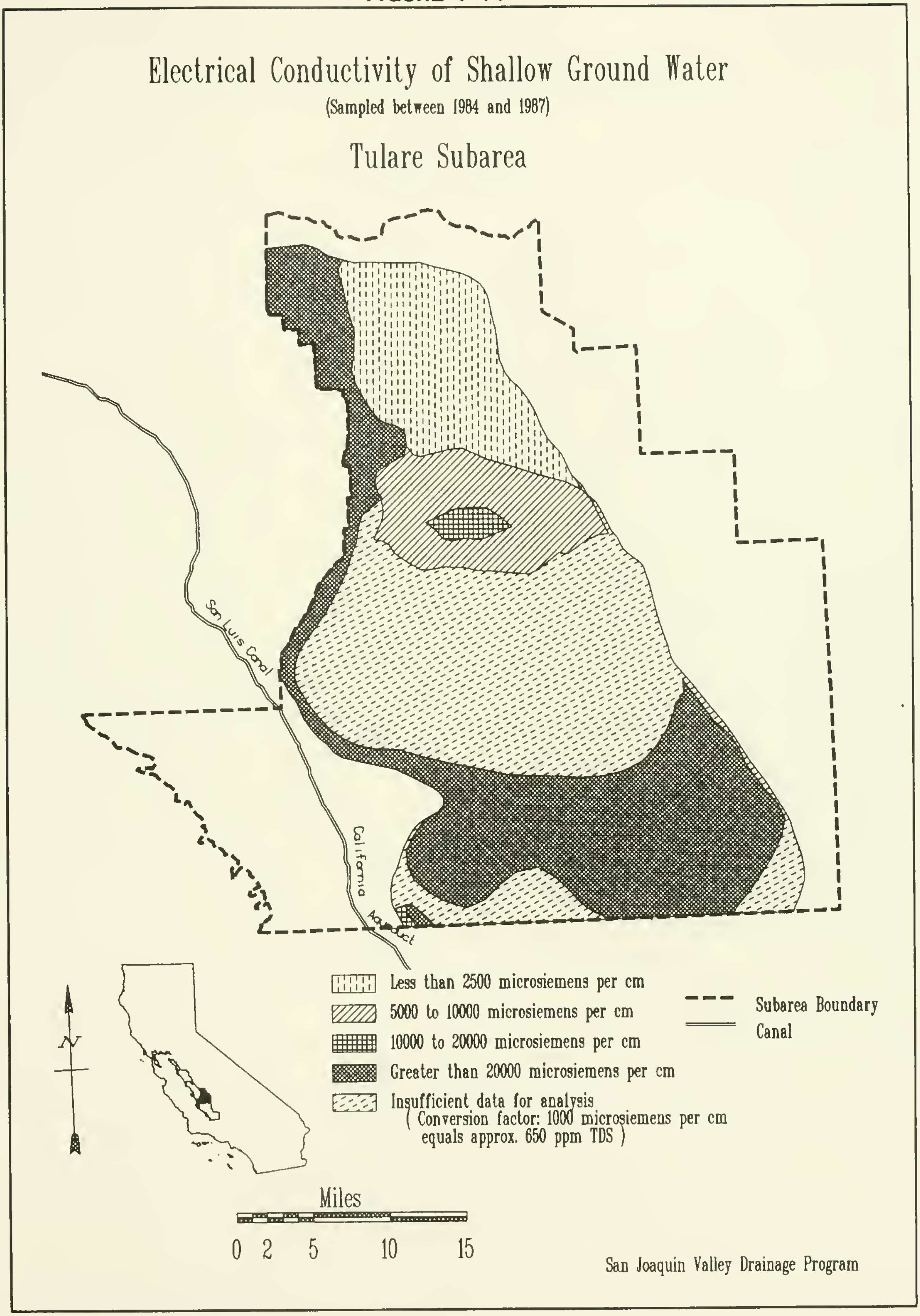

Electrical Conductivity of Shallow Ground Water
(Sampled between 1984 and 1987)
Tulare Subarea
San Luis Canal
California Aqueduct
Less than 2500 microsiemens per cm
5000 to 10000 microsiemens per cm
10000 to 20000 microsiemens per cm
Greater than 20000 microsiemens per cm
Insufficient data for analysis
(Conversion factor: 1000 microsiemens per cm equals approx. 650 ppm TDS)
Subarea Boundary
Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-T4

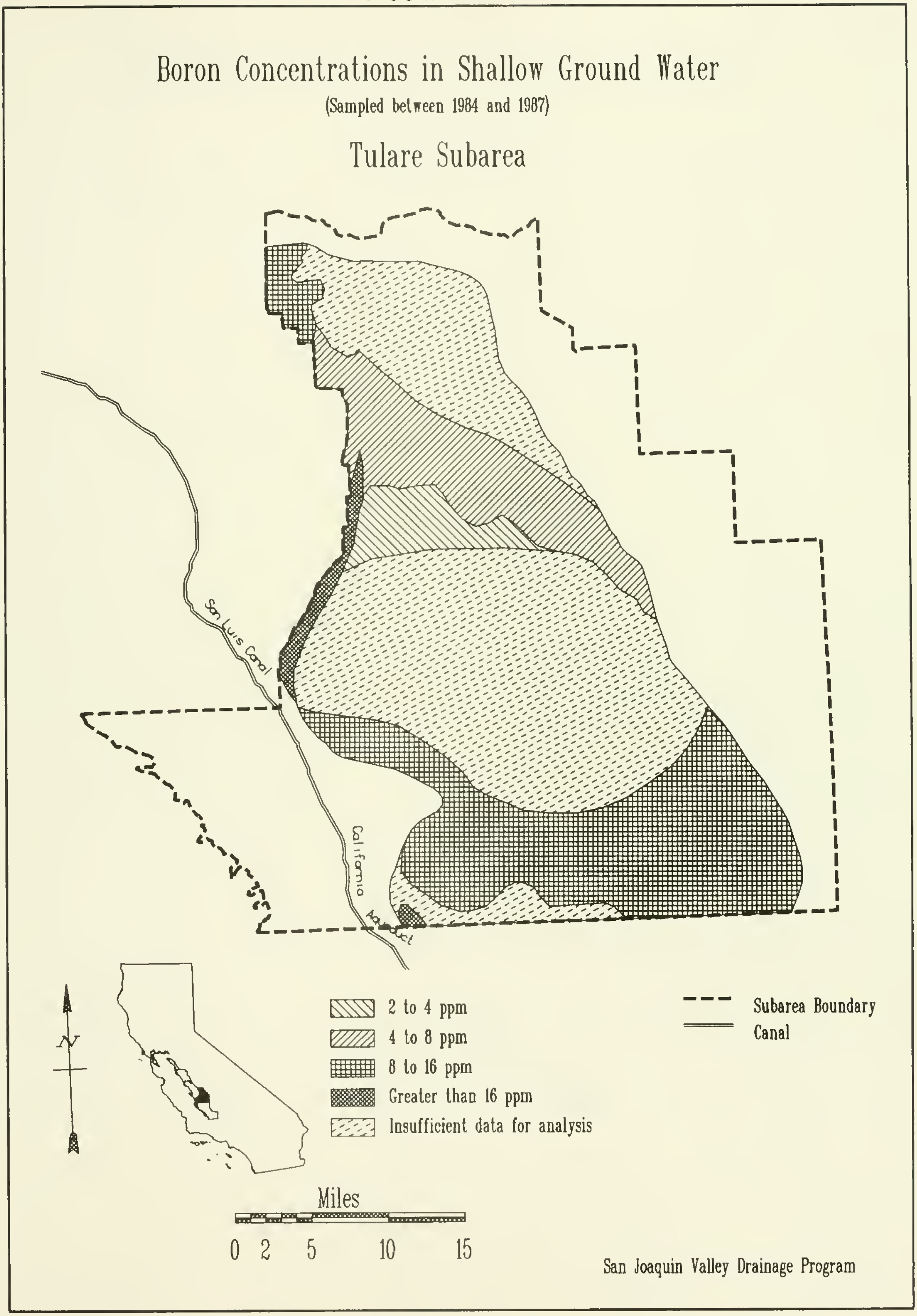

Boron Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Tulare Subarea
San Luis Canal
California Aqueduct
2 to 4 ppm
4 to 8 ppm
8 to 16 ppm
Greater than 16 ppm
Insufficient data for analysis
Subarea Boundary
Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-T5

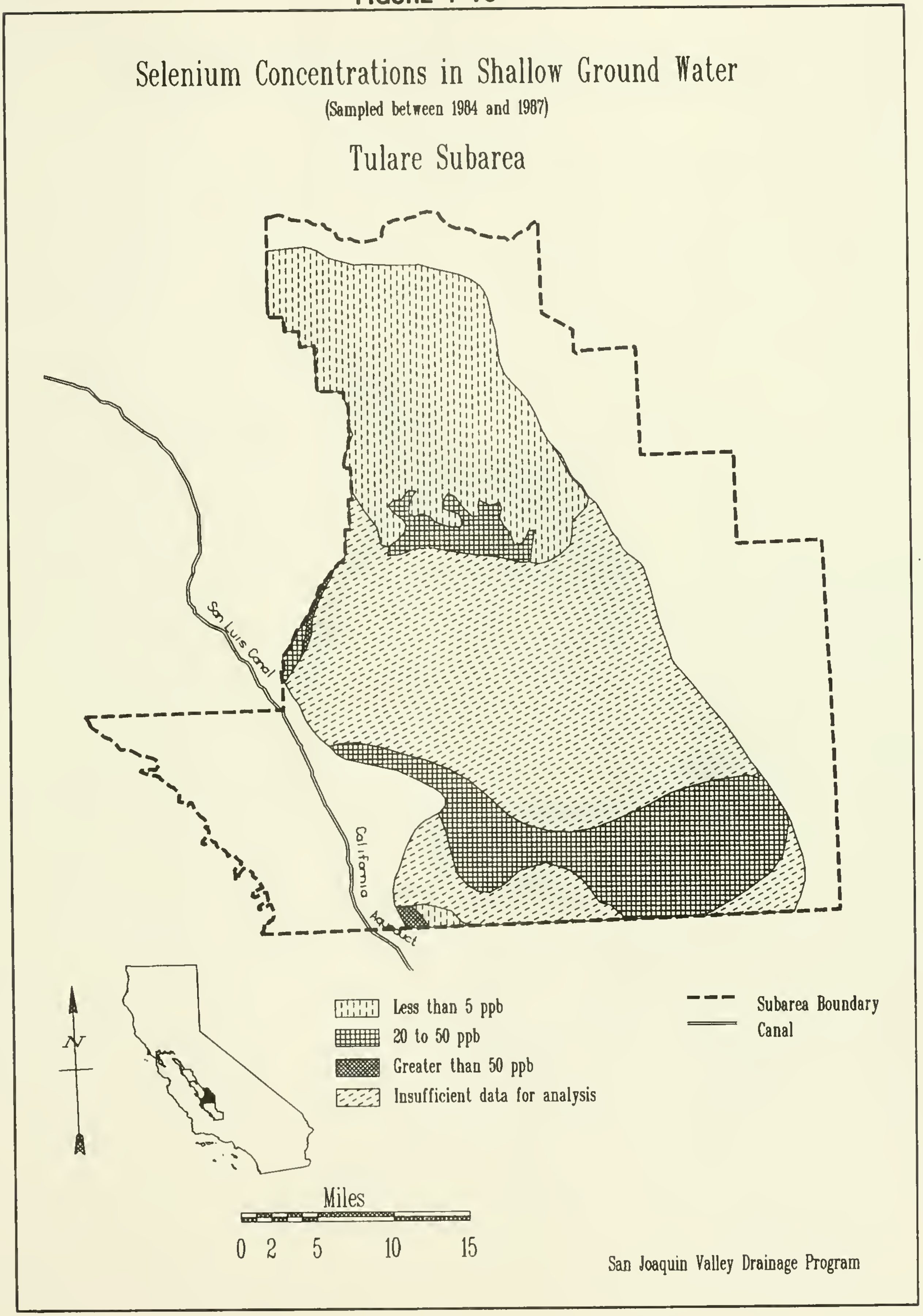

Selenium Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Tulare Subarea
San Luis Canal
California Aqueduct
Less than 5 ppb
20 to 50 ppb
Greater than 50 ppb
Insufficient data for analysis
Subarea Boundary
Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-T6

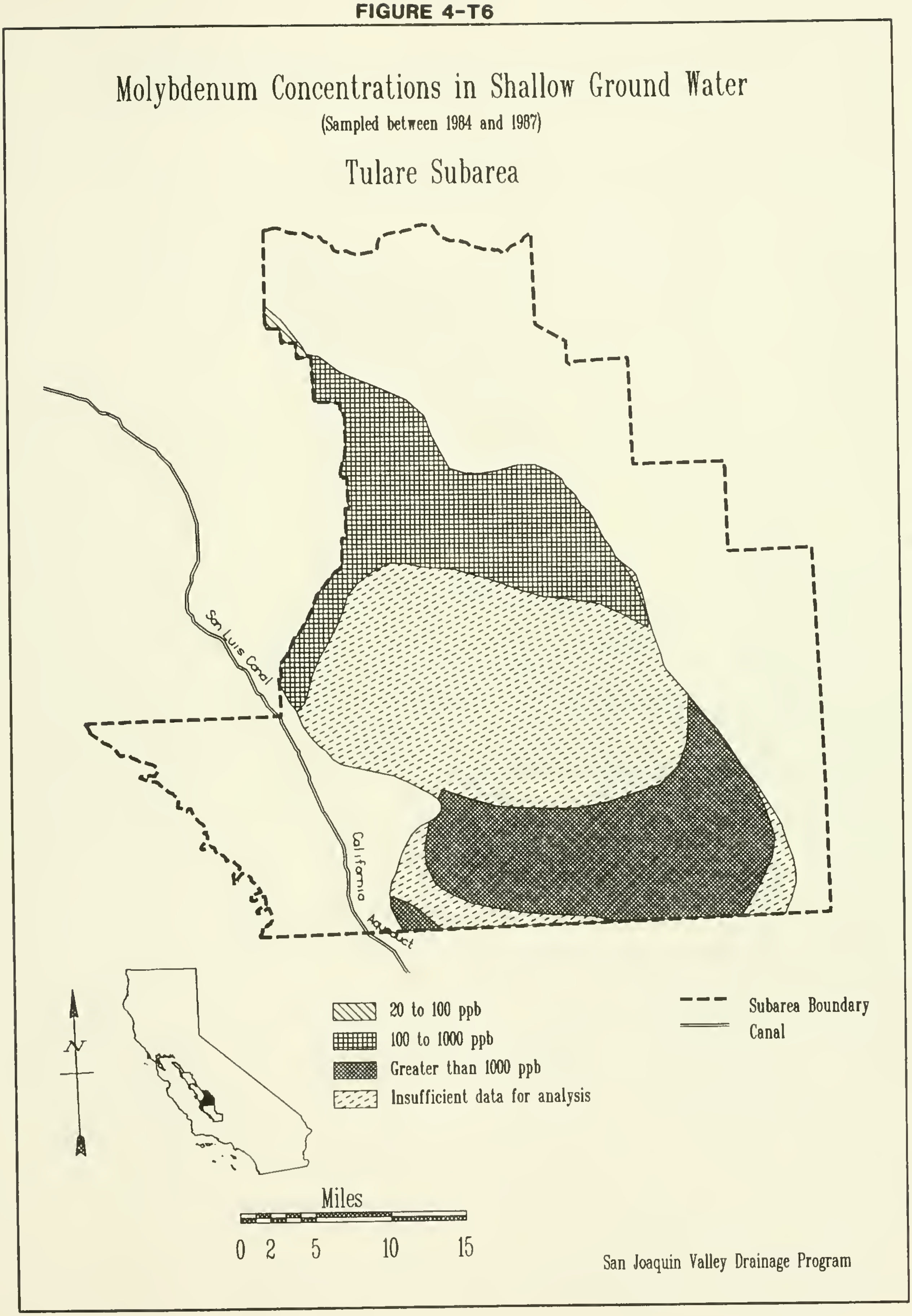
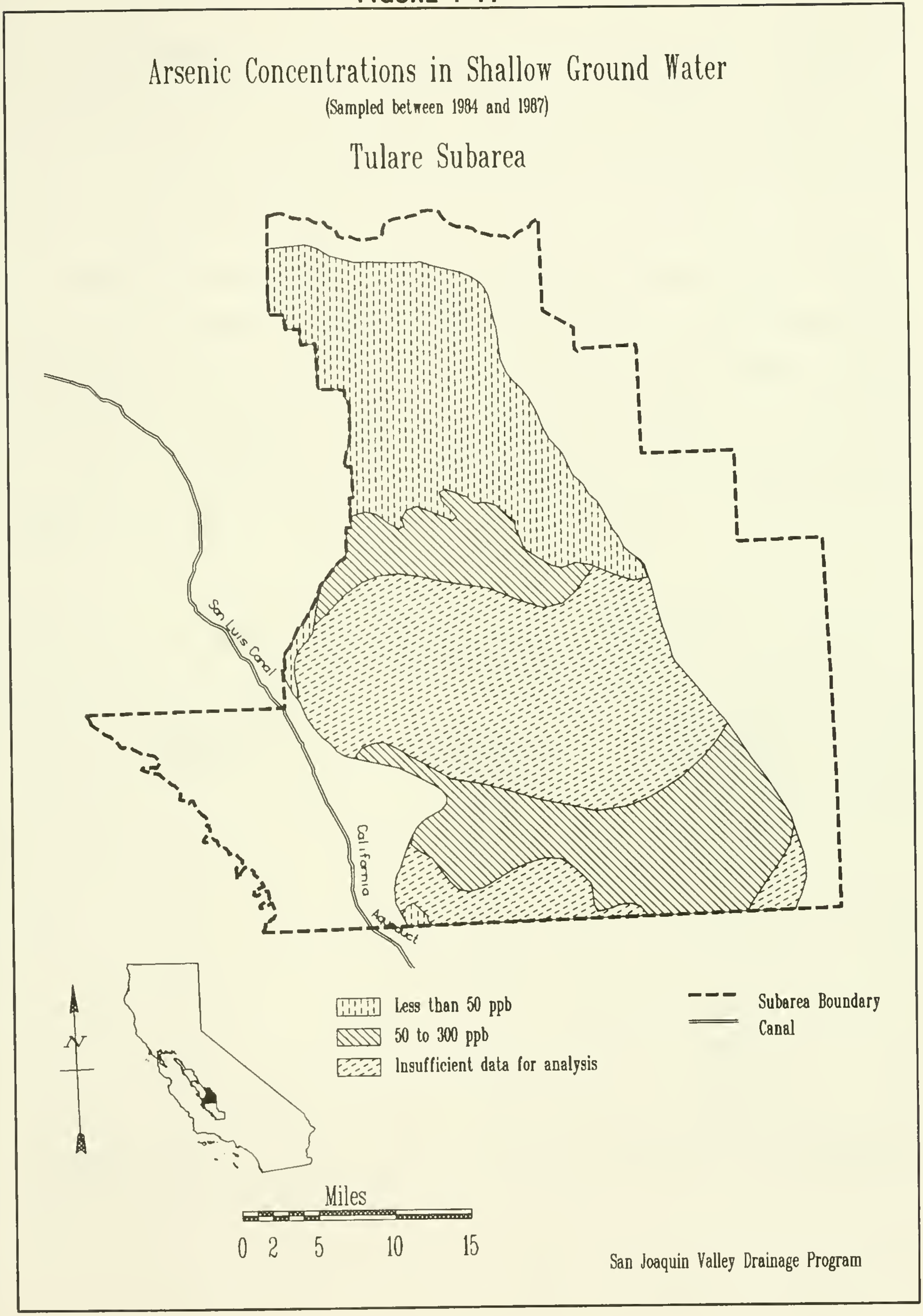

Molybdenum Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Tulare Subarea
San Luis Canal
California Aqueduct
20 to 100 ppb
100 to 1000 ppb
Greater than 1000 ppb
Insufficient data for analysis
Subarea Boundary
Canal
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-T7


Arsenic Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Tulare Subarea
San Luis Canal
California Aqueduct
N
Less than 50 ppb
50 to 300 ppb
Insufficient data for analysis
Subarea Boundary
Canal
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

Water-budget analyses indicate that, on a regional scale, the amount of land affected by shallow ground-water levels in the subarea will increase significantly if present water supply and drainage conditions continue. Salt load in the shallow ground water is accumulating in the subarea at the rate of about 1.3 million tons/year.

Generally, the high water-table conditions impair water quality, crop selection, and crop productivity. Significant changes in land use and cropping patterns can be expected in the subarea as growers attempt to prolong the productivity of their land despite increasing salinity.

Annual problem-water volumes have been estimated for each water-quality zone in this subarea. (See Table 4-12 and Figure 4-T8.)

Table 4-12

ANNUAL PROBLEM-WATER VOLUME - TULARE SUBAREA
(For Year 2000)

Water-Quality Zone	Drained Area (acres)	Problem-Water Volume (acre-ft)
A	1,000	1,000*
B	33,000	25,000
C	6,000	4,000
D	10,000	7,000
E	27,000	20,000
F	49,000	36,000
TOTAL	126,000	92,000

*For convenience, the 1,000 acre-ft of Zone A is included in the computation for Zone A, Kern Subarea.

Planning objectives for agriculture. For planning purposes, it is assumed that the amount of land drained will increase from about 42,000 acres in 1987 to about 126,000 acres by the year 2000, as growers act to manage shallow ground water.

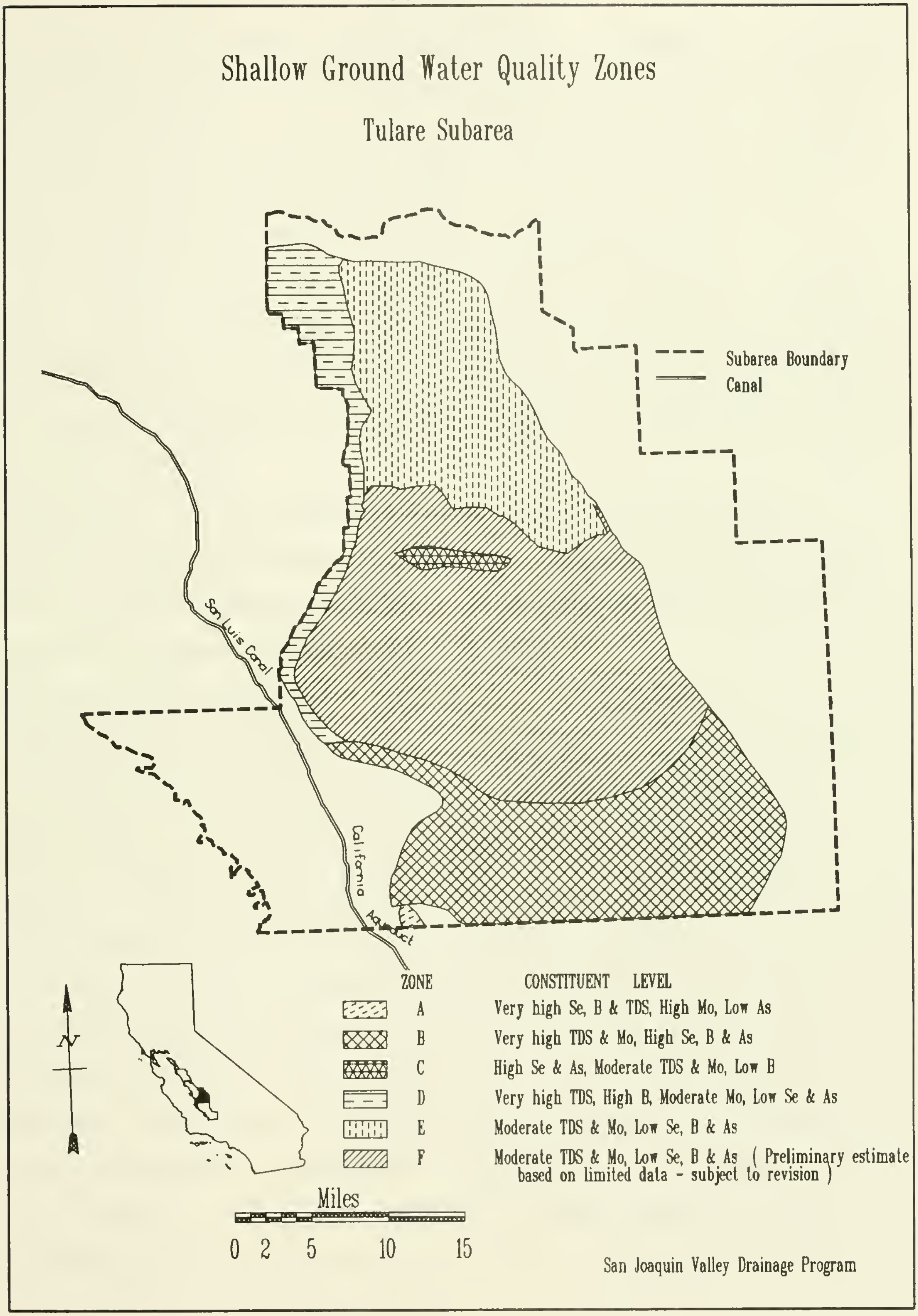
The agricultural objective for the Tulare Subarea is to dispose of or manage the problem-water volume shown in Table 4-12 by a combination of source-control measures or other appropriate alternatives so the drainage water is not a problem to agriculture or to other public values (e.g., water quality, public health, and fish and wildlife).

Public Health

Conditions. The potential public health problems of this subarea relate to the use of evaporation ponds to dispose of selenium-contaminated drainage water.

There are 16 drainage-water evaporation ponds in the Tulare Subarea. Biological residue data exist for 13 of these ponds (all but 4-J Corporation, Nickell, and Smith Farms). Samples of the following organisms collected from valley evaporation ponds exceeded the CDHS selenium guidance level: ruddy ducks collected from Meyers Ranch in February 1988 (White et al., 1989); widgeongrass collected from Morris Farms in June 1987 (S. A. Ford and D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]); ruddy ducks and American avocet eggs collected from Pryse Farms in 1987-1988 (Skorupa and Ohlendorf, 1989; White et al., 1989); northern shovelers and ruddy ducks collected from Tulare Lake Drainage District Hacienda Ranch in 1983-1985 (D. A. Barnum and D. S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; widgeongrass, ruddy ducks, northern shovelers, American coots, and duck eggs collected from the Tulare Lake Drainage District South in 1982-1987 (Barnum and Gilmer, 1985; Skorupa and Ohlendorf, 1989; White et al.,

FIGURE 4-T8


Shallow Ground Water Quality Zones
Tulare Subarea
Subarea Boundary
Canal
San Luis Canal
California Aqueduct
ZONE
CONSTITUENT LEVEL
A Very high Se, B & TDS, High Mo, Low As
B Very high TDS & Mo, High Se, B & As
C High Se & As, Moderate TDS & Mo, Low B
D Very high TDS, High B, Moderate Mo, Low Se & As
E Moderate TDS & Mo, Low Se, B & As
F Moderate TDS & Mo, Low Se, B & As (Preliminary estimate based on limited data - subject to revision)
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

1987; White et al., 1989); and ruddy ducks collected from Westlake Farms South in February 1988 (White et al., 1989). Widgeongrass (an aquatic plant), all types of birds (including ducks and waterfowl), and bird eggs have all been identified as species collected by foragers in the San Joaquin Basin (M. Campbell and L. C. Christensen, UCD, Davis, CA [unpublished data]).

The "1987 California Hunting Regulations, Part III (Waterfowl)" advised hunters to limit or discontinue their consumption of American coots taken from irrigation/evaporation ponds in the northwestern Kern County and southwestern Kings County area because of elevated concentrations of selenium in the birds' tissues (CDFG, 1987a).

Objectives. The public health objectives are to determine ways to discourage hunting and foraging at contaminated ponds, and to monitor selenium and other potential substances of concern in all relevant exposure sources to assure that humans are not exposed to unsafe levels.

Fish and Wildlife Resources

Description. Historically, the Tulare Subarea was dominated by Tulare Lake, which at its highest elevation flooded 760-800 square miles (about 490,000-510,000 acres) (Thompson, 1892; USBR, 1970). Today, however, that productive freshwater lake and its surrounding wetland habitat have been replaced primarily by agricultural lands. With the exception of a few small towns, the lower reach of the Kings River, Elk Bayou (Kaweah River), Tule River, Deer Creek, and White River, and somewhat more than 10,000 acres of land managed primarily for wildlife, almost the entire remainder of the 562,000-acre Tulare Subarea is in agricultural land uses. The wildlife areas include: Allensworth Ecological Reserve (about 500 acres), Creighton Ranch Preserve (about 3,300 acres), Lemoore Naval Air Station (about 400 acres), Pixley NWR (about 6,000 acres), and four duck clubs (unknown acreage greater

than 100 acres). Remnant habitats protected within these areas include California prairie, ephemeral pond, riparian forest, San Joaquin saltbush, vernal pool, and wetland. Wildlife species associated with these habitats include blunt-nosed leopard lizard, greater sandhill crane, Nelson's antelope ground squirrel, San Joaquin kit fox, shorebirds, Tipton kangaroo rat, and waterfowl.

Other than irrigation canals and drainage ditches, the principal flowing water features in the subarea are the lower Kings River, Elk Bayou (Kaweah River), Tule River, Deer Creek, and White River. The river and creeks support an assortment of warm-water fish species including sunfish, catfish, and native nongame fishes.

Newly created habitats in the subarea include 16 drainage-water evaporation ponds developed during the past 15 years (covering a total of about 5,900 acres, about 80 percent of all the evaporation pond acreage in the valley) and an expanding acreage of agroforestry plantations (most planted in the last 2-4 years). The evaporation ponds are heavily used by aquatic birds for wintering and breeding habitat (Barnum, 1989; Hoffman-Floerke, 1985; Schroeder et al., 1988; Tribbey, 1988; Tribbey and Beckingham, 1986). Studies conducted by CSU, Fresno for the SJVDP have revealed that agroforestry plantations provide perching, nesting, and burrowing habitat for a variety of birds and mammals.

Problems. Contamination field studies have documented elevated concentrations of selenium (an indicator of contamination by subsurface agricultural drainage water) in water (greater than 5 ppb) and/or sediments (greater than 0.5 ppm, dry weight) collected from all of the 16 evaporation ponds in the Tulare Subarea including: Barbizon Farms, Bowman Farms, Four-J Corporation, Jackson & Williams Farms (aka Liberty Farms), Martin Farms,

Meyers Ranch, Morris Farms, Nickell, Pryse Farms, Smith Farms, Stone Land Company, Tulare Lake Drainage District Hacienda, Tulare Lake Drainage District North, Tulare Lake Drainage District South, Westlake Farms North (#1 & #2), and Westlake Farms South (#3) (Westcot et al., 1988a). Food-chain organisms have been collected from 12 of the 16 evaporation ponds in the subarea and chemically analyzed for selenium. Concentrations of selenium toxic to mallards (equal to or greater than 7 ppm, dry weight) have been found in food-chain organisms collected from 7 of those 12 ponds including: Bowman Farms, Martin Farms, Morris Farms, Pryse Farms, Tulare Lake Drainage District Hacienda, Tulare Lake Drainage District South, and Westlake Farms South (#3) (D. A. Barnum and D. S Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; S. A. Ford and D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]; T. Heyne, CSUF, and M. Kie, CDFG, Fresno, CA [unpublished data]; and White et al., 1987). Studies of reproduction and/or survival of aquatic birds have been conducted at 9 of the subarea's 16 ponds. Significantly elevated frequencies of adverse biological effects (that are believed to be contaminant-related) have been documented in breeding aquatic birds at five ponds including: Martin Farms, Pryse Farms, Tulare Lake Drainage District Hacienda, Tulare Lake Drainage District South, and Westlake Farms North (#1 & #2) (Ohlendorf, 1988; Skorupa, 1989; Skorupa and Ohlendorf, 1989; Skorupa and Ohlendorf, 1988).

Water, sediments, and food-chain organisms have been collected from Pixley NWR and sediments and food-chain organisms have been collected from Deer Creek, and these samples have been chemically analyzed. Selenium concentrations in samples of water and sediments collected from these areas have not been elevated (Schroeder et al., 1988). Selenium concentrations in samples of food-chain organisms collected from these areas have not exceeded

known toxic thresholds (Schroeder et al., 1988). No contaminant-related studies of reproduction or survival of fish or wildlife have been undertaken at these areas.

It is currently unknown whether agroforestry plantations in the subarea are contaminated by drainage-water substances of concern such that they pose a contaminant threat to wildlife using the sites.

Apparently, no drainage water has been used to help satisfy water needs for public or private wildlife areas in the Tulare Subarea. Creighton Ranch Preserve and Pixley NWR need 9,300 acre-ft/yr of firm, nontoxic, freshwater to satisfy optimum management objectives. At least 400 acre-ft/yr of firm, nontoxic, freshwater is needed to satisfy optimum management objectives for private duck clubs in the subarea. None of these public or private wildlife areas currently has any reliable supply of nontoxic freshwater. Wildlife agencies and interests have determined that the Tulare Basin (including the Westlands, Tulare, and Kern Subareas) is 5,000 acres short of the wetland habitat needed to support international waterfowl population objectives.

Instream fishery flow needs for the Kings River, Elk Bayou (Kaweah River), Tule River, Deer Creek, and White River are unknown.

Objectives. Protection of remaining wildlife habitats and populations in the subarea will probably require acquisition and management of some lands by wildlife organizations and/or appropriate financial incentives for private landowners to forgo conversion of remaining wetlands (e.g., through acquisition of perpetual wetlands easements). The acquisition and development of new wetlands (complete with adequate, firm supplies of nontoxic freshwater) would likely provide migratory birds and a broad variety of other wetland-dependent wildlife species with additional protection from drainage-water

contaminants. Additional, high quality wetland habitat would be expected to preferentially draw some wildlife away from evaporation ponds, thereby reducing the numbers of individuals exposed to drainage-water contaminants and/or decreasing exposure frequencies and/or durations. Consequently, the frequencies and/or severity of contaminant-caused biological effects associated with the ponds and public health risks associated with game birds using the ponds would be expected to be reduced.

Additional biological monitoring and field and laboratory research are needed to fill in data gaps and determine, for example: (1) What the concentrations of drainage contaminants are in water, sediments, and food-chain organisms in all fish and wildlife habitats in the subarea that are, or have been, exposed to drainage water, (2) whether adverse biological effects are continuing at evaporation ponds studied to date and/or at ponds which have not yet been studied, (3) whether newly established agroforestry plantations pose drainage-related contaminant threats to wildlife using the sites, and (4) the quantity, quality, and schedule of instream fishery flows needed in the Kings River, Elk Bayou (Kaweah River), Tule River, Deer Creek, and White River to support viable fisheries.

Concerted action is needed to ensure that those drainage-contaminated evaporation ponds in the Tulare Subarea at which significantly elevated frequencies of adverse biological effects have been documented are managed to keep wildlife out, operated in a wildlife-safe manner, or are decontaminated and closed. No other habitat decontamination and restoration needs have been identified to date in the subarea.

It appears that no subsurface drainage water has been intentionally used to help satisfy water needs for public or private wildlife areas in the subarea; therefore, no substitute water supply objective has been established.

Improvement of wildlife resources in the Tulare Subarea would occur if: Pixley NWR and Creighton Ranch were provided with an additional firm, nontoxic freshwater supply totaling 9,300 acre-ft/yr, and private duck clubs in the subarea were provided with an additional quantity of firm, nontoxic freshwater greater than 400 acre-ft/yr (these volumes are equal to the additional water needed to satisfy optimum management objectives for existing lands); and/or 5,000 acres of new wetlands and associated water supplies were provided in the subarea.

Available Technologies Alternative

The available technologies alternative for the Tulare Subarea for the year 2000 is comprised of three components: (1) Actions to sustain irrigated agriculture, (2) actions to protect public health, and (3) actions to protect and restore fish and wildlife and their habitats. Each component is discussed and presented in the following sections. The State water-quality objectives for surface water are viewed as constraints that would be met simultaneously with accomplishment of these actions, and the technical analyses have taken this into account--limiting actions that do meet the constraints.

Actions to sustain agriculture. Tables 4-13 through 4-17 present options that have been applied to reduce problem-water volumes in water-quality Zones B, C, D, E, and F (Figure 4-T8). (Zone A, which is very small, is included in Zone A of the Kern Subarea.)

From examination and comparison of these tables, the following can be concluded about the agricultural component of the alternative:

- Source-control options included in each zone would provide a reduction in problem-water volume ranging from 52 percent in Zone C to 42 percent in Zone B.

Table 4-13

AVAILABLE TECHNOLOGIES ALTERNATIVE
TULARE SUBAREA - ZONE B

(Estimated volume of problem water to be managed by year 2000 = 25,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	15,000	825,000	6,000
A-2, A-3	Improve irrigation management	5	15,000	75,000	3,000
A-9	Manage water table to increase evapotranspiration	30	7,500	225,000	1,500
	Drainage-Water Reuse				
D-1	Irrigate saltbush (b)	473	3,100	1,466,300	10,100
	Drainage-Water Disposal				
E-5	Use existing evaporation ponds (c)	240	1,200	288,000	4,400
	TOTALS			2,879,300	25,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 2,300 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

Table 4-14

AVAILABLE TECHNOLOGIES ALTERNATIVE
TULARE SUBAREA - ZONE C

(Estimated volume of problem water to be managed by year 2000 = 4,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	3,000	165,000	1,200
A-2, A-3	Improve irrigation management	5	3,000	15,000	600
A-9	Manage water table to increase evapotranspiration	30	1,500	45,000	300
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	200	125,000	1,300
D-1	Irrigate saltbush (c)	241	100	24,100	300
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (d)	154	100	15,400	300
	TOTALS			389,500	4,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 200 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Includes 100 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(d) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

Table 4-15

AVAILABLE TECHNOLOGIES ALTERNATIVE
TULARE SUBAREA - ZONE D

(Estimated volume of problem water to be managed by year 2000 = 7,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	5,000	275,000	2,000
A-2, A-3	Improve irrigation management	5	5,000	25,000	1,000
A-9	Manage water table to increase evapotranspiration	30	2,500	75,000	500
	Drainage-Water Reuse				
D-1	Irrigate saltbush (b)	473	700	331,100	2,300
	Drainage-Water Disposal				
E-5	Use existing evaporation ponds (c)	35	300	10,500	1,200
	TOTALS			716,600	7,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 500 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

Table 4-16

AVAILABLE TECHNOLOGIES ALTERNATIVE
TULARE SUBAREA - ZONE E

(Estimated volume of problem water to be managed by year 2000 = 20,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	14,000	770,000	5,600
A-2, A-3	Improve irrigation management	5	14,000	70,000	2,800
A-9	Manage water table to increase evapotranspiration	30	7,000	210,000	1,400
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	1,400	875,000	8,000
D-1	Irrigate saltbush (c)	473	500	236,500	1,700
	Drainage-Water Disposal				
E-5	Construct new evaporation ponds (d)	1,205	150	180,750	500
	TOTALS			2,342,250	20,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 1,000 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Includes 400 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(d) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

Table 4-17

AVAILABLE TECHNOLOGIES ALTERNATIVE
TULARE SUBAREA - ZONE F

(Estimated volume of problem water to be managed by year 2000 = 36,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	24,000	1,320,000	9,600
A-2, A-3	Improve irrigation management	5	24,000	120,000	4,800
A-9	Manage water table to increase evapotranspiration	30	12,000	360,000	2,400
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	2,500	1,562,500	14,400
D-1	Irrigate saltbush (c)	473	900	425,700	3,000
	Drainage-Water Disposal				
E-5	Construct new evaporation ponds (d)	1,205	400	482,000	1,800
	TOTALS			4,270,200	36,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 1,900 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Includes 700 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(d) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

- Drainage-water reuse options included in each zone would provide a reduction in problem-water volume ranging from 40 percent in Zones B and C to 48 percent in Zones E and F.
- Ground-water management options would be used in conjunction with reuse in Zone C. Generally, however, aquifer characteristics in most of the subarea are unfavorable for effective pumping of ground water as a "method to draw" or "means for drawing" down the deep percolation resulting from reuse of drainage water.
- Existing evaporation ponds (1,500 acres) would be used in Zones B and D and new evaporation ponds (550 acres) would be constructed in Zones E and F (assuming ongoing analyses demonstrate the problem water in these zones to be relatively low in selenium). It should be noted that the large differences in the costs of using existing evaporation ponds ($240/acre of pond in Zone B compared to $35/acre of pond in Zone D) reflect directly differences in the selenium concentrations of the drainage water and the costs of keeping contaminated ponds bird-free.

Costs of the agricultural component are calculated as follows:

1. Average annual cost of source-control options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$4{,}575{,}000}{42{,}700\ \text{AF}} = \$107/\text{AF}$$

2. Average annual cost of combined reuse, disposal, and ground-water options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$6{,}022{,}850}{49{,}300\ \text{AF}} = \$122/\text{AF}$$

3. Average annual cost of the agricultural component:

$$\frac{\text{costs } (\$4{,}575{,}000 + \$6{,}022{,}850)}{\text{volumes } (42{,}700\ \text{AF} + 49{,}300\ \text{AF})} = \frac{\$10{,}597{,}850}{92{,}000\ \text{AF}} = \$115\ \text{AF of problem water}$$

$$\text{costs } (\$115/\text{AF}) \times \text{drainage factor } (0.75\ \text{AF/acre}) = \$86/\text{acre of contributing land}$$

To summarize, the set of actions to sustain irrigated agriculture in the Tulare Subarea under this alternative is: (1) Conserve irrigation water through improvements in technology and management, (2) reuse drainage water on eucalyptus trees, (3) drain the eucalyptus trees, (4) reuse the resultant drainage water on saltbush, (5) drain the saltbush, and (6) dispose of the resultant drainage water by either draining or pumping from beneath the saltbush, and storing the remaining problem water in evaporation ponds or in the semiconfined aquifer.

Actions to minimize public health risks. General actions that could be continued or undertaken to minimize public health risks in the Tulare Subarea are listed in the "Public Health Component" section located near the beginning of this chapter. Public health warnings are presently needed for the Meyers Ranch evaporation ponds, Morris Farms ponds, Tulare Lake Drainage District (TLDD), Hacienda Ranch ponds, TLDD south pond, and Westlake Farms south ponds.

Actions that would protect, restore, and provide substitute water supplies for fish and wildlife resources. Protection of existing wildlife resources in the Tulare Subarea could occur through: (1) Protection of remaining, unprotected wetlands in the subarea through acquisition and management by wildlife organizations or by use of other legal protections (unprotected wetlands in the subarea [e.g., duck club wetlands] currently total approximately 100 acres), (2) provision of a firm, nontoxic freshwater supply to all remaining wetlands-wildlife areas (the freshwater supply deficit for the subarea totals more than 9,700 acre-ft/yr), and/or (3) acquisition, development, and management of new wetlands (up to 5,000 acres of additional wetlands complete with adequate, firm supplies of nontoxic freshwater [about 20,000 acre-ft/yr] are needed in the Tulare Basin [Westlands, Tulare, and Kern Subareas] to support international waterfowl population objectives). If

combined with hazing programs at the ponds, the provision of adequate, firm, nontoxic freshwater supplies for existing wetlands-wildlife areas and/or the purchase and development of new wetlands would reduce some of the ongoing and anticipated adverse effects upon aquatic birds created by some evaporation ponds in the subarea. Drainage-water evaporation ponds in the valley need to be treated as special cases, because although they are not specifically managed as wildlife habitat, they nonetheless experience considerable use by aquatic birds. Due to contamination of some ponds, they can also be lethal, attractive nuisances. Actions that are currently being taken to address this problem include signing of mutual "monitoring and mitigation agreements" between pond owners and the DFG which require hazing at toxic ponds. Additionally, field testing of various techniques to make the ponds bird-safe or bird-free is occurring at selected ponds but could be greatly expanded. A third set of actions that would further reduce adverse effects at the ponds is the development and management of new wetlands habitat in their vicinity.

The provision of adequate, additional volumes of firm, nontoxic freshwater supplies to existing and needed wetlands in the Tulare Subarea would go a long way toward addressing drainage-related and other fish and wildlife resource problems. Provision of such waters could help protect existing and increased wildlife populations. The SJVDP has estimated that approximately 200,000 acre-ft/yr of irrigation water currently used on the west side and southern end of the San Joaquin Valley could be conserved through on-farm water conservation, improved drainage management, drainage-water reuse, and ground-water pumping. Under the available technologies alternative, some of that conserved water would be reallocated to existing wetlands-wildlife areas in the subarea to satisfy existing needs (9,700 acre-feet/yr).

KERN SUBAREA

The Kern Subarea (Figure 4-K1) includes about 1,891 square miles (1,210,000 acres) of predominantly rural land in Kern County. The northern boundary is the Kern County line, the eastern and southern boundaries include the beds of ancestral Kern Lake and Buena Vista Lake, and the western boundary lies along the base of the foothills of the Coast Ranges (including several hill areas such as Wheeler Ridge, Elk Hills, and Lost Hills). The major land use is irrigated agriculture.

Significant commercial and residential development is occurring in the subarea in the environs of Bakersfield and along major highway corridors. The estimated 1989 population of the subarea is 30,000.

The lands identified as having potential drainage problems are located primarily in the beds (now dry) of ancestral lakes (Buena Vista, Goose, and Kern) and along the northwestern margin of the subarea, in the Lost Hills area.

Irrigated Agriculture

Water supply. Irrigation water supplies in the Kern Subarea consist of water imports from the Delta, diversions from east-side streams such as the Kern River and Poso Creek, Friant-Kern Canal deliveries from the San Joaquin River, and local ground water.

Historically, the primary water supply for irrigation was local ground water and diversions from east-side rivers. Supplemental water has been provided by the Friant-Kern Canal since the early 1950's and by the California Aqueduct since the late 1960's. The annual firm irrigation water supply from the Delta is about 1.2 million acre-feet. An additional 0.8 million acre-feet/year is provided by a combination of ground-water pumping, Friant-Kern Canal deliveries, and direct diversions from east-side streams.

Delivery of SWP water is managed largely by the Kern County Water Agency, a confederation of 16 water and irrigation districts empowered to: contract for and manage a common water supply; construct flood control, storage, and drainage facilities; and represent the common interests of the water districts. The agency also manages a ground-water recharge program, which during some wet years has recharged local aquifers (not in drainage problem area) with up to 750,000 acre-feet.

The quality of water delivered from the Delta ranges from 250 to 450 ppm salt (TDS). Higher quality water is obtained from the Kern River, other east-side streams, and Friant-Kern Canal deliveries. Ground-water supplies are generally much more saline (1,000 to 10,000 ppm TDS), a condition requiring either blending with surface-water supplies or special water management practices.

Drainage-related water quality. Figure 4-K2 shows the shallow ground water in the subarea at depths of 0-5, 5-10, and 10-20 feet below the land surface in 1987. The shallow ground water contains a wide range of concentrations of salt, boron, selenium, molybdenum, and arsenic. The areal distribution of these dissolved constituents in 1987 is shown in Figures 4-K3, 4-K4, 4-K5, 4-K6, and 4-K7, respectively.

There are about 1,300 acres of evaporation ponds in the subarea that are used to dispose of about 6,000 acre-feet of drainage annually. An additional 4,000 acre-feet of drainage is recycled by blending with irrigation water supplies. Drainage water generally contains salts in the range of 10,000 to 20,000 ppm TDS.

FIGURE 4-K1

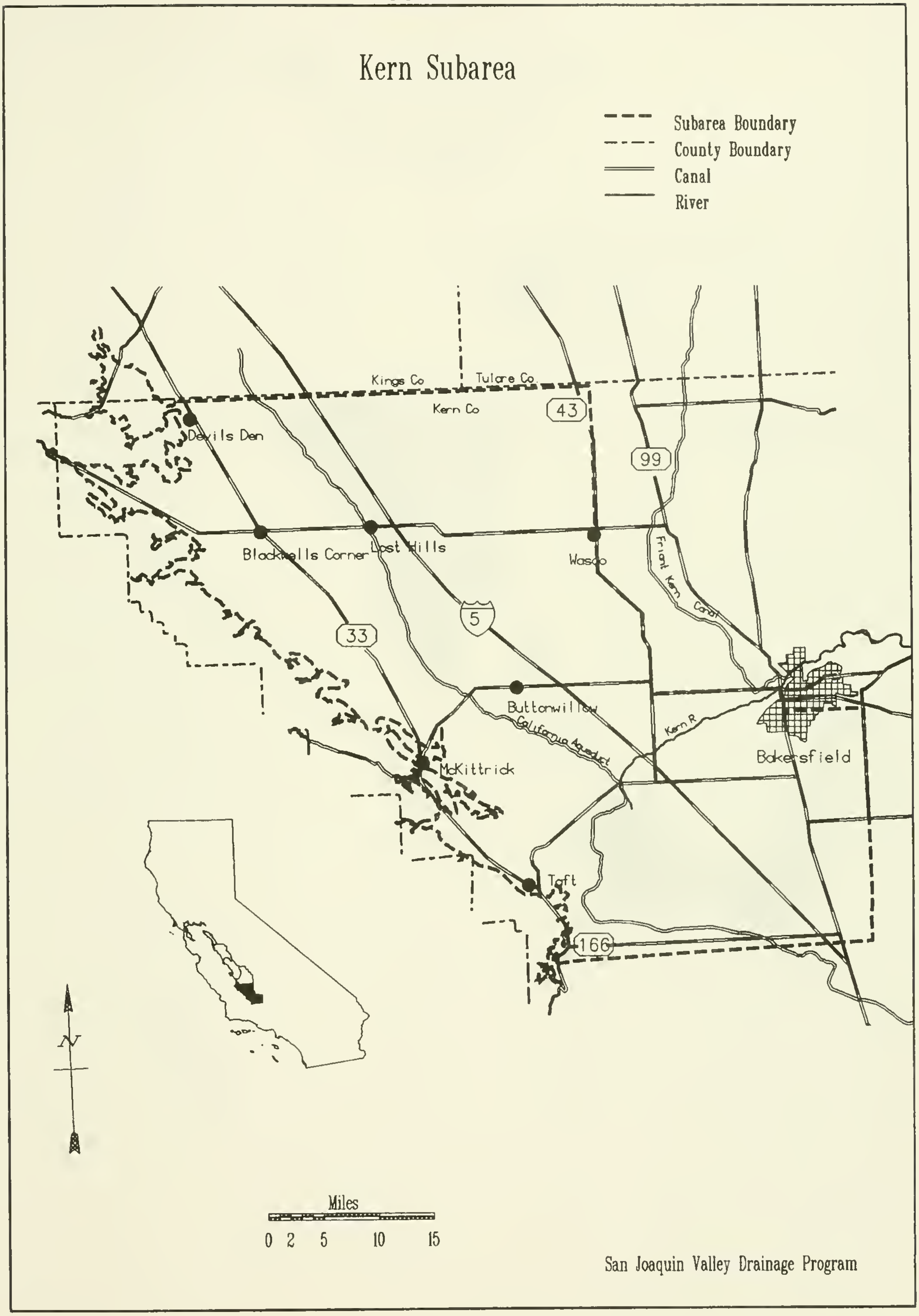
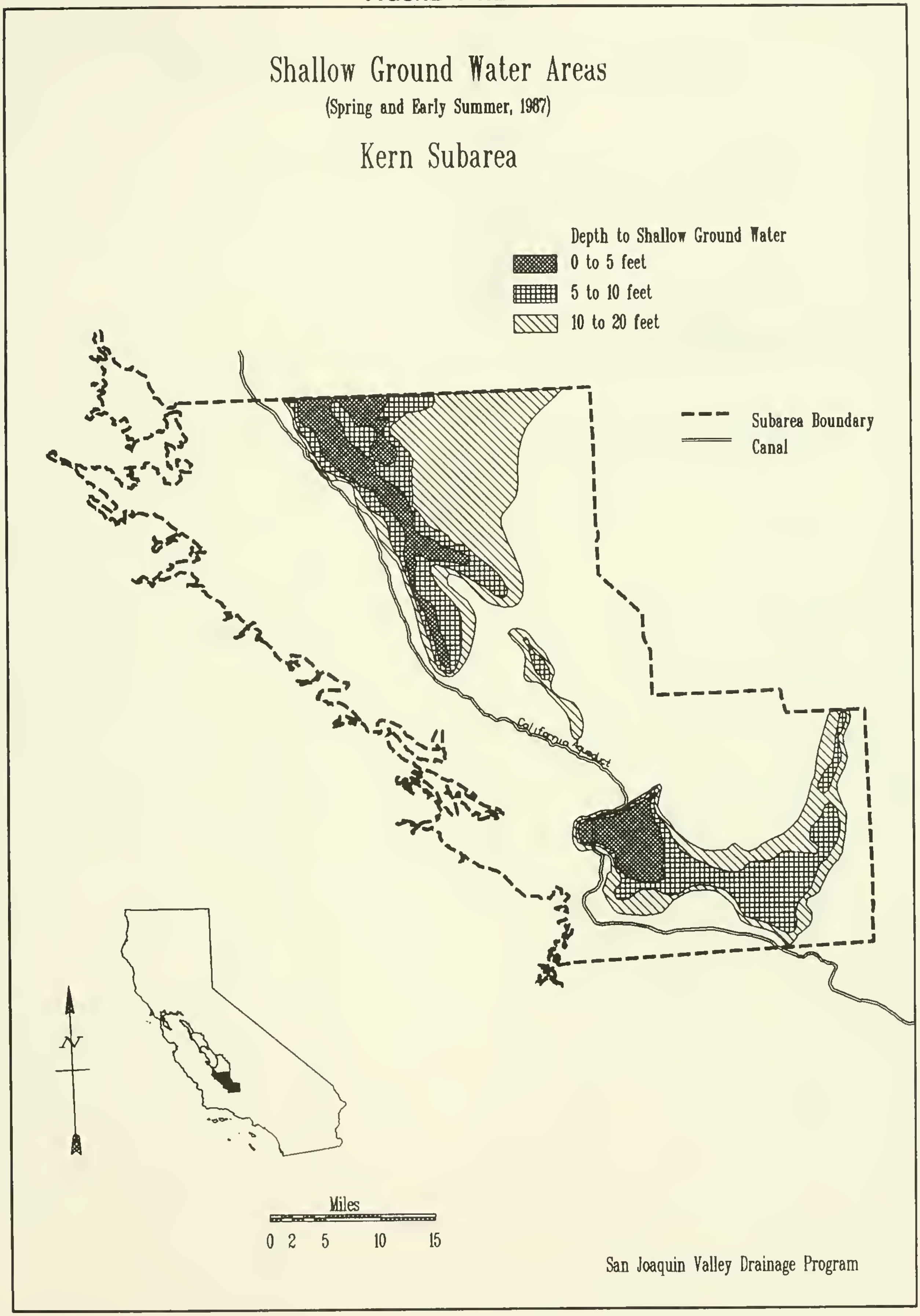

Kern Subarea
Subarea Boundary
County Boundary
Canal
River
Kings Co
Tulare Co
Kern Co
43
99
Devils Den
Blackwells Corner
Lost Hills
Wasco
Friant Kern Canal
5
33
Buttonwillow
California Aqueduct
Kern R
Bakersfield
McKittrick
Taft
166
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-K2



Shallow Ground Water Areas
(Spring and Early Summer, 1987)
Kern Subarea
Depth to Shallow Ground Water
0 to 5 feet
5 to 10 feet
10 to 20 feet
Subarea Boundary
Canal
California Aqueduct
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-K3

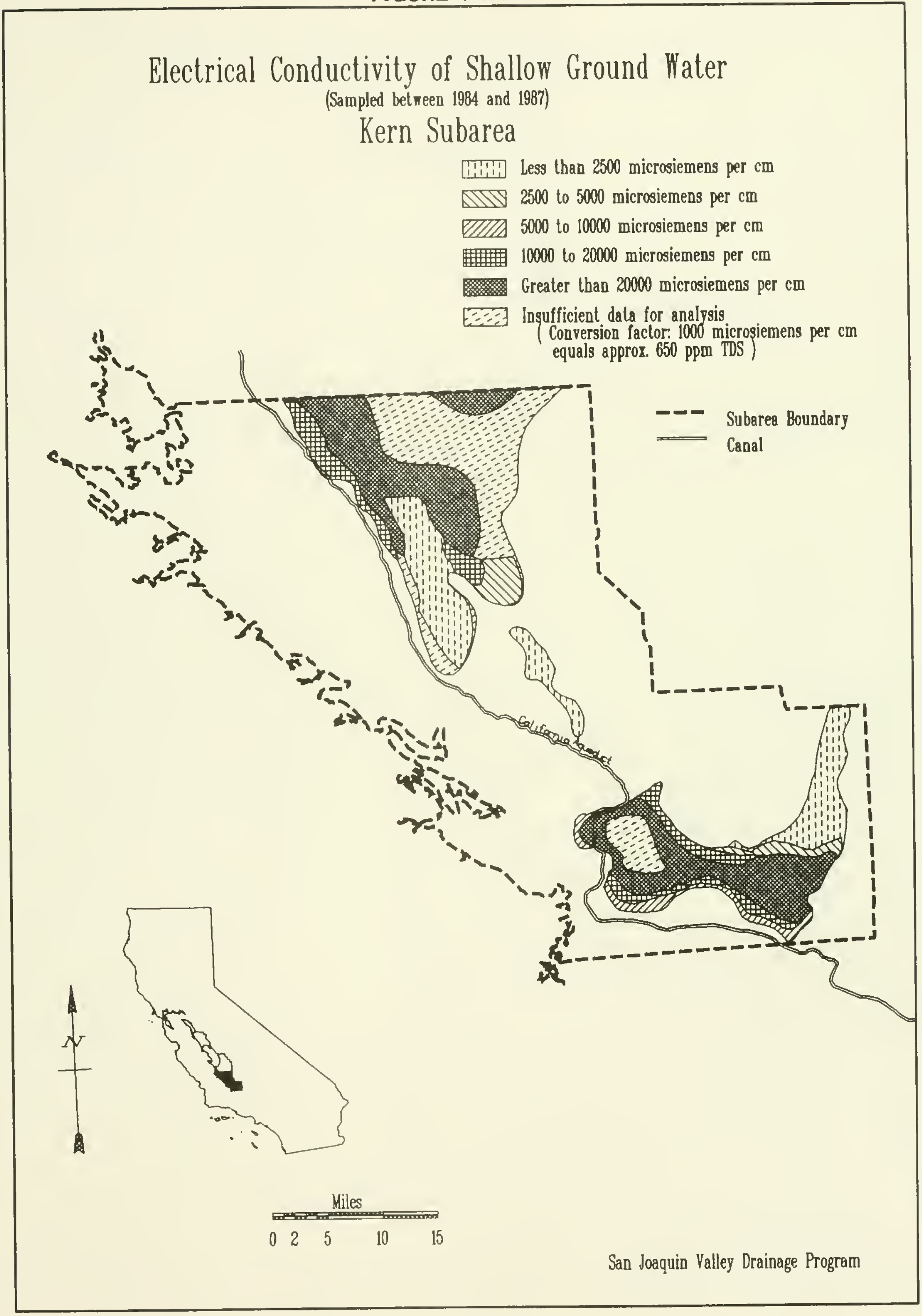
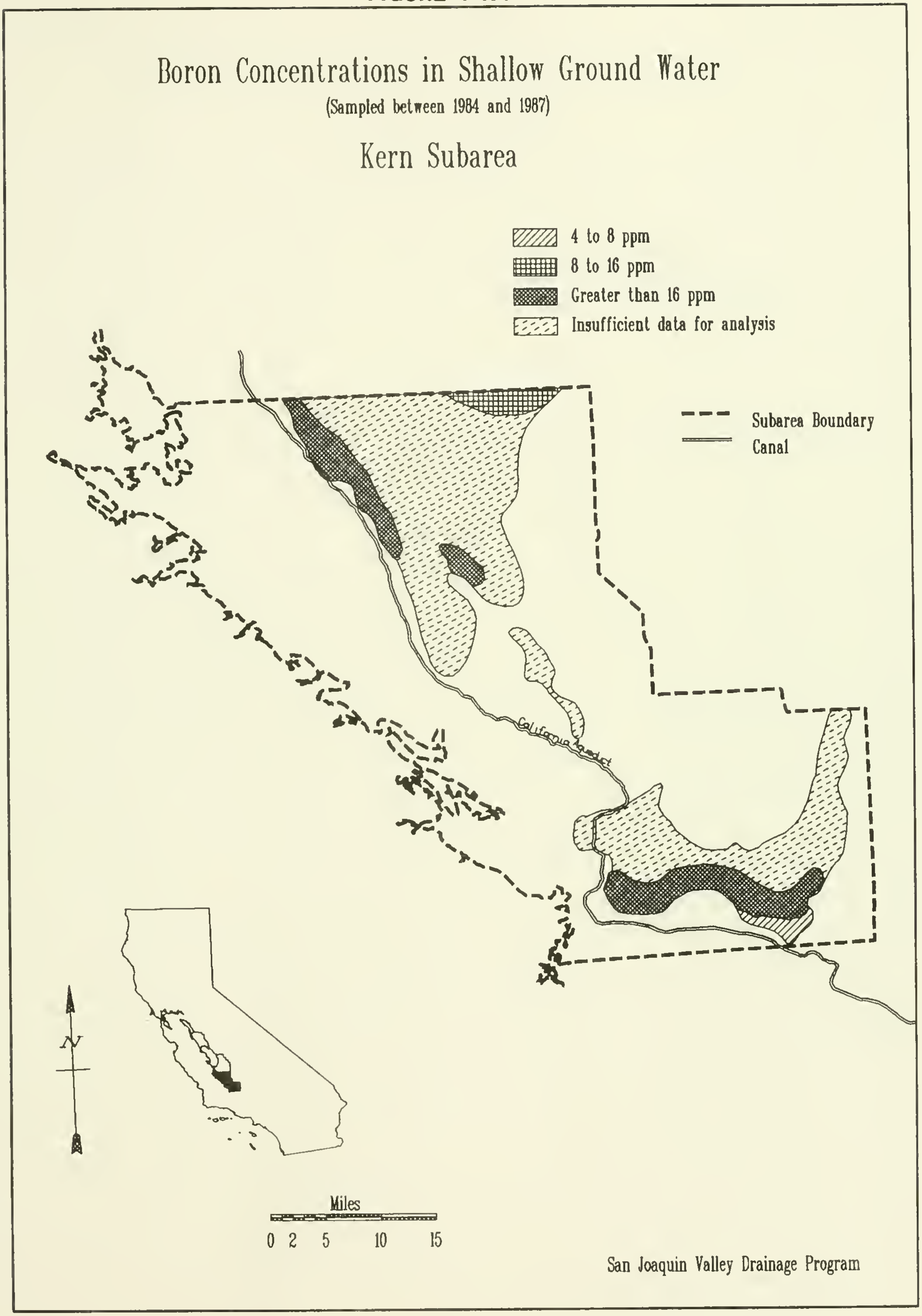

Electrical Conductivity of Shallow Ground Water
(Sampled between 1984 and 1987)
Kern Subarea
Less than 2500 microsiemens per cm
2500 to 5000 microsiemens per cm
5000 to 10000 microsiemens per cm
10000 to 20000 microsiemens per cm
Greater than 20000 microsiemens per cm
Insufficient data for analysis
(Conversion factor: 1000 microsiemens per cm equals approx. 650 ppm TDS)
Subarea Boundary
Canal
California Aqueduct
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-K4



Boron Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Kern Subarea
4 to 8 ppm
8 to 16 ppm
Greater than 16 ppm
Insufficient data for analysis
Subarea Boundary
Canal
California Aqueduct
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-K5

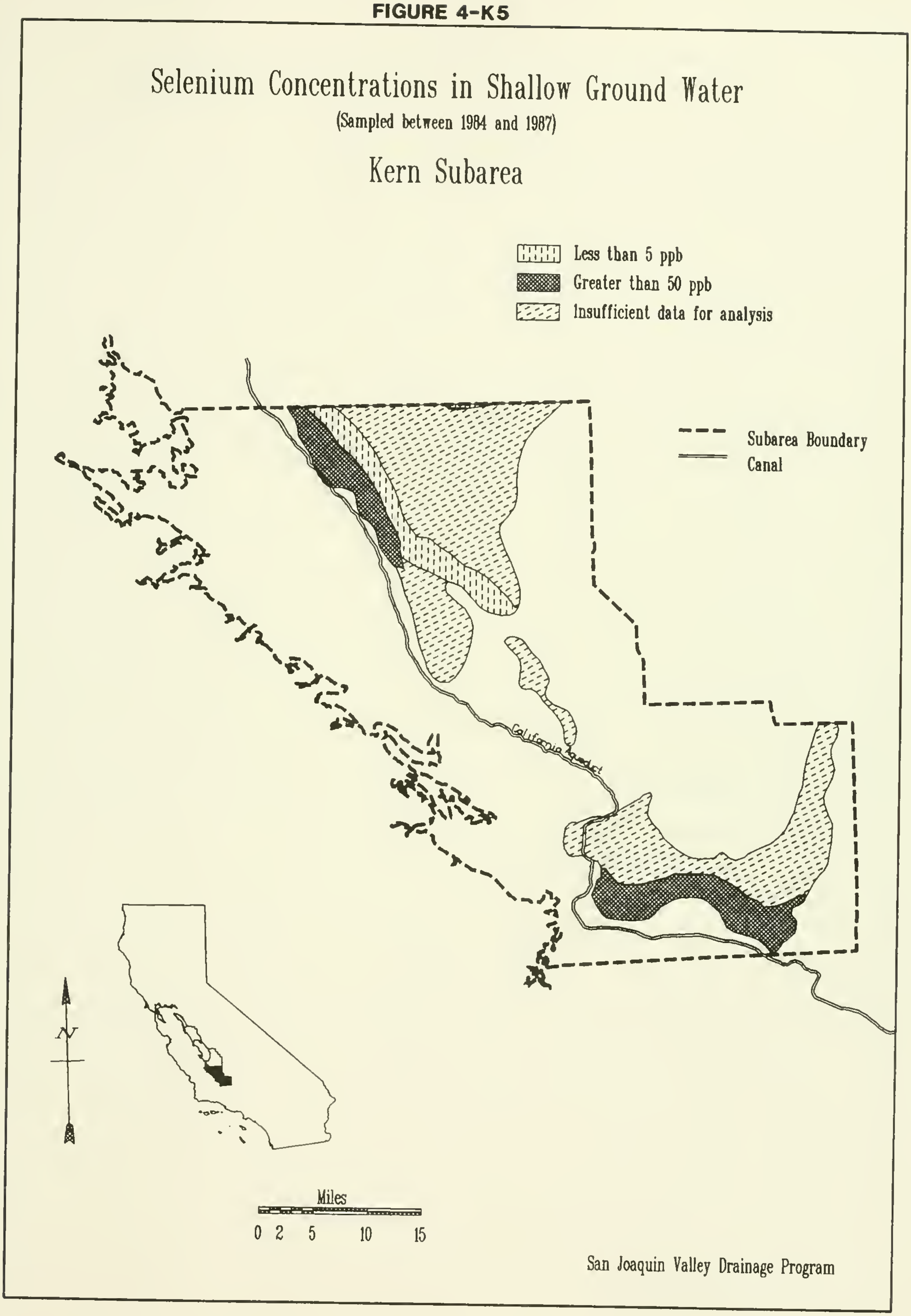
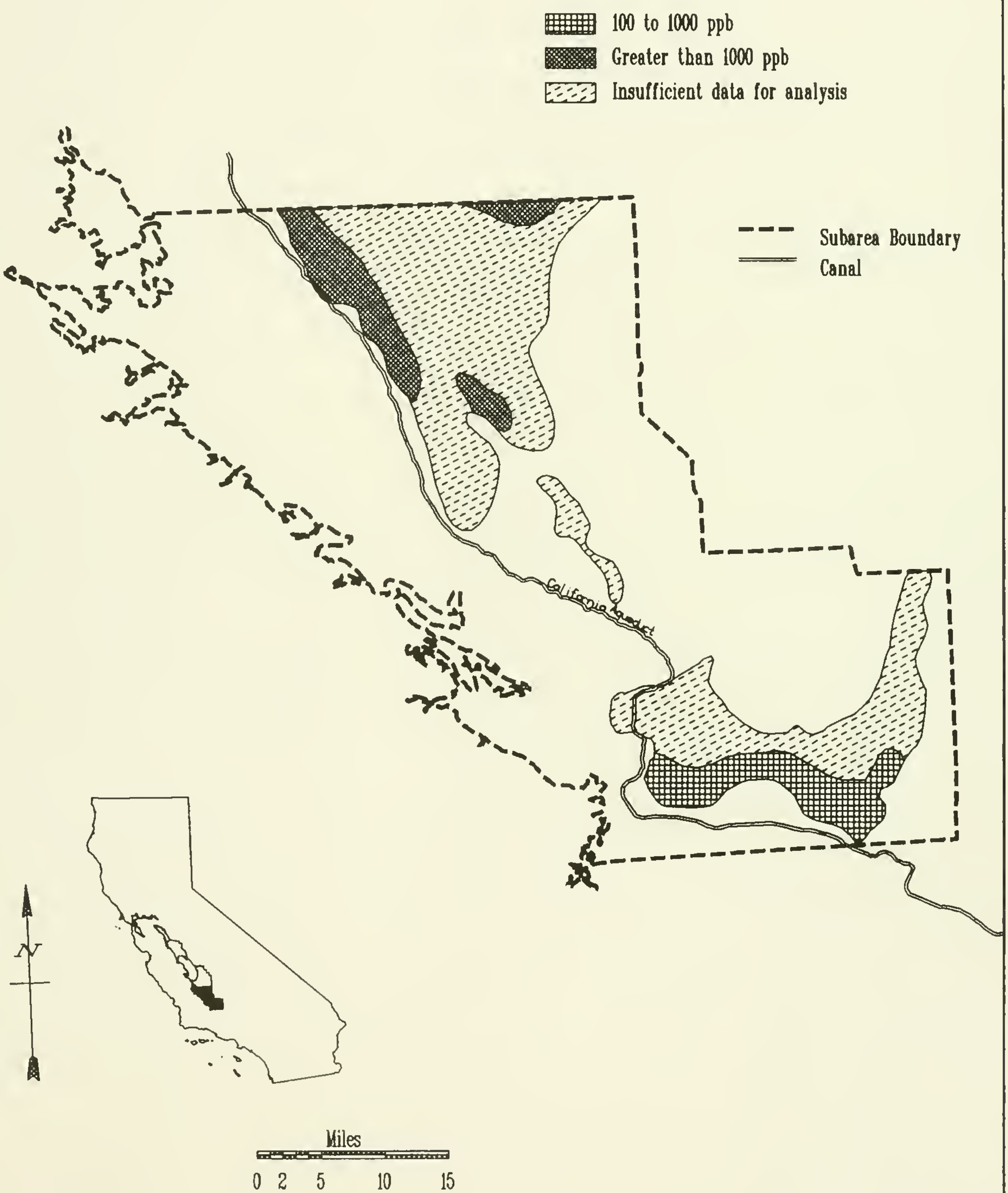

Selenium Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Kern Subarea
Less than 5 ppb
Greater than 50 ppb
Insufficient data for analysis
Subarea Boundary
Canal
California Aqueduct
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

FIGURE 4-K6

Molybdenum Concentrations in Shallow Ground Water

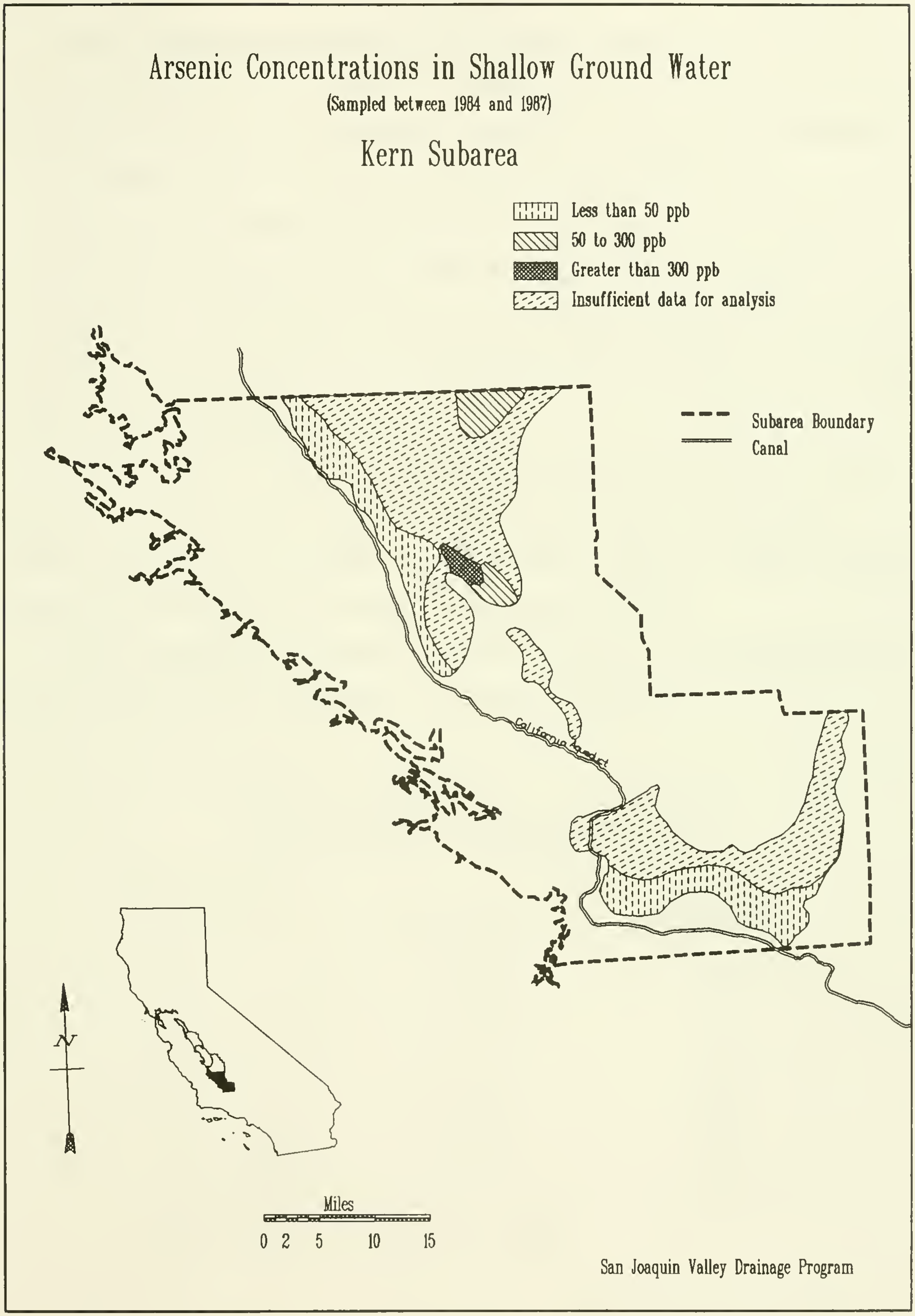
(Sampled between 1984 and 1987)

Kern Subarea



San Joaquin Valley Drainage Program

FIGURE 4-K7



Arsenic Concentrations in Shallow Ground Water
(Sampled between 1984 and 1987)
Kern Subarea
Less than 50 ppb
50 to 300 ppb
Greater than 300 ppb
Insufficient data for analysis
Subarea Boundary
Canal
California Aqueduct
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

Agricultural drainage problem. Approximately 64,000 acres of agricultural land in this subarea has ground-water levels within 5 feet of the land surface during part of the year. In 1977, there were only 28,000 acres in this category; the forecast for the year 2000 is 100,000 acres.

Water-budget analyses indicate that, on a regional scale, the lands affected by shallow ground-water levels in the subarea will increase significantly if present water supply and drainage conditions continue. Salt load in the shallow ground water is accumulating in the subarea at the rate of about 1.1 million tons/year.

Generally, the high water-table conditions impair water quality, crop selection, and crop productivity. Significant changes in land use and cropping patterns can be expected in the subarea as growers attempt to prolong the productivity of their land despite increasing salinity.

Annual problem-water volumes have been estimated for each water-quality zone in this subarea. (See Table 4-18 and Figure 4-K8.)

Table 4-18

ANNUAL PROBLEM-WATER VOLUME - KERN SUBAREA
(For Year 2000)

Water-Quality Zone	Drained Area (acres)	Problem-Water Volume (acre-ft)
A	23,000	18,000*
B	2,000	1,500
C	4,000	3,000
D	31,000	23,000
TOTAL*	60,000	45,500*

*Includes Zone A of the Tulare Subarea.

Planning objectives for agriculture. For planning purposes, it is assumed that the amount of land drained will increase from about 11,000 acres in 1987 to about 60,000 acres by the year 2000, as growers act to manage shallow ground water.

The agricultural objective for the Kern Subarea is to dispose of or manage the problem-water volume by a combination of source-control measures or other appropriate alternatives so the drainage water is not a problem to agriculture or to other public values (e.g., water quality, public health, and fish and wildlife).

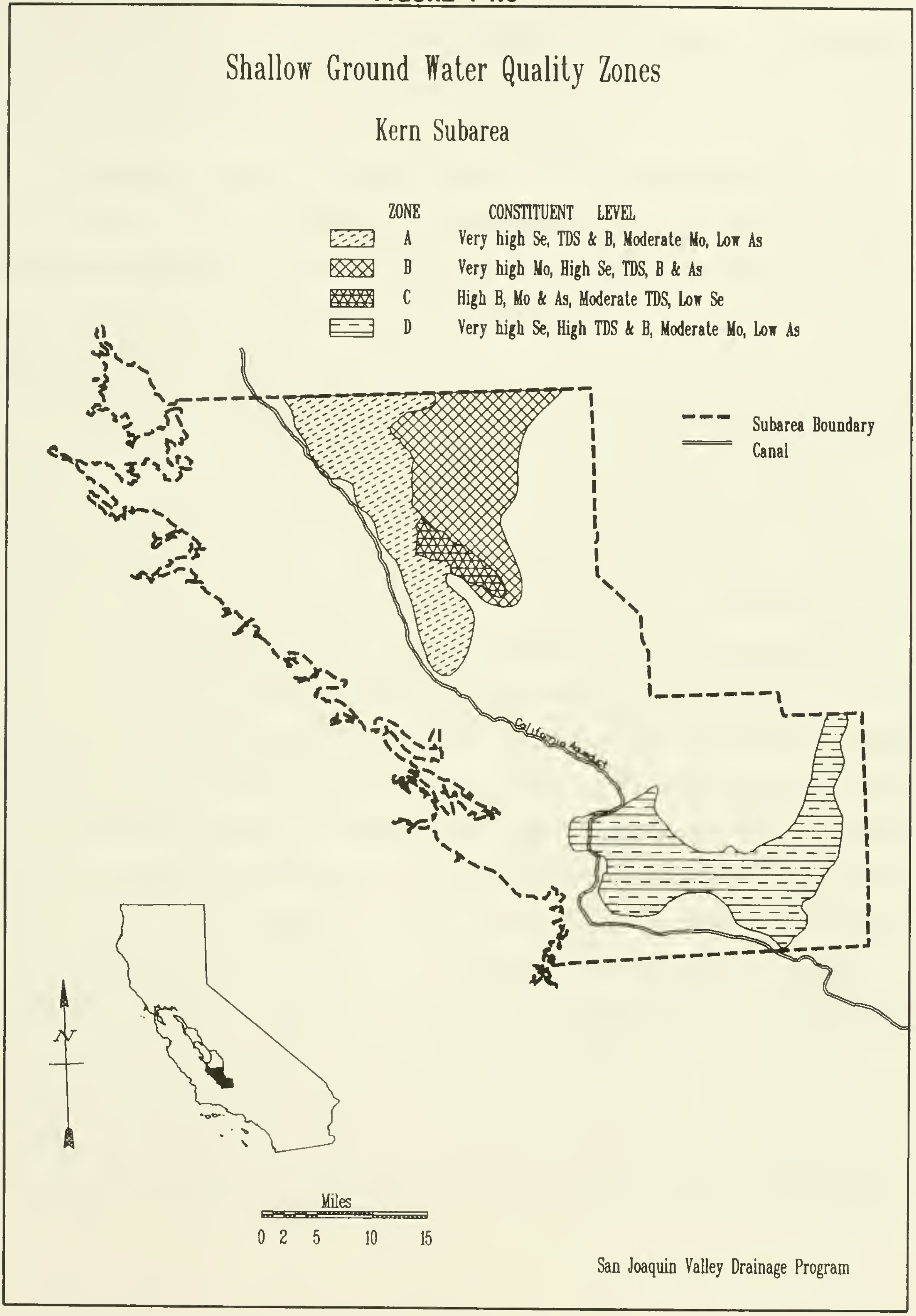
Public Health

Conditions. The potential public health problems of this subarea relate to the use of evaporation ponds to dispose of selenium-contaminated drainage water.

There are five drainage-water evaporation ponds in the Kern Subarea. There are biological residue data from four of these ponds (Sam Andrews, Carmel Ranch, Lost Hills Ranch, and Westfarmers). Samples of widgeongrass, ruddy ducks, and American avocet eggs collected from the Westfarmers evaporation ponds in 1986-1988 exceeded the CDHS selenium guidance level (S. A. Ford and D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]; Schroeder et al., 1988; Skorupa and Ohlendorf, 1989; White et al., 1989). Widgeongrass (an aquatic plant), ducks, and bird eggs have all been identified as species collected by foragers in the San Joaquin Basin (M. Campbell and L. C. Christensen, UCD, Davis, CA [unpublished data]).

The "1987 California Hunting Regulations, Part III (Waterfowl)" advised hunters to limit or discontinue their consumption of American coots taken from

FIGURE 4-K8



Shallow Ground Water Quality Zones
Kern Subarea
ZONE
CONSTITUENT LEVEL
A Very high Se, TDS & B, Moderate Mo, Low As
B Very high Mo, High Se, TDS, B & As
C High B, Mo & As, Moderate TDS, Low Se
D Very high Se, High TDS & B, Moderate Mo, Low As
Subarea Boundary
Canal
California Aqueduct
N
Miles
0 2 5 10 15
San Joaquin Valley Drainage Program

irrigation/evaporation ponds in the northwestern Kern County and southwestern Kings County area because of elevated concentrations of selenium in the birds' tissues (CDFG, 1987a).

Objectives. The public health objectives are to determine ways to discourage hunting and foraging at contaminated ponds and to monitor selenium and other potential substances of concern in all relevant exposure sources to assure that humans are not exposed to unsafe levels.

Fish and Wildlife Resources

Description. With the exception of a portion of Bakersfield, a few small towns, the lower reach of the Kern River and Poso Creek, and somewhat more than 17,000 acres of land managed primarily for wildlife, much of the Kern Subarea is in agricultural land uses. The wildlife areas include: Duck Pond (Area of Critical Environmental Concern, about 320 acres), Goose Lake (Area of Critical Environmental Concern, about 40 acres), Kern Lake Preserve (about 80 acres), Kern NWR (about 10,600 acres), Kern River Parkway (about 760 acres), Paine Preserve (about 900 acres), Poso Creek Conservation Easement (about 70 acres), Tule Elk State Reserve (about 1,000 acres), and 45-50 duck clubs (unknown acreage, but assumed greater than about 3,300 acres). Remnant habitats protected within these areas include California prairie, riparian forest, San Joaquin saltbush, vernal pool, and wetland. These habitats are host to endangered plant species, or candidates for such status, such as Bakersfield saltbush and hispid bird's beak. Wildlife species associated with these habitats include blunt-nosed leopard lizard, Buena Vista Lake shrew, Nelson's antelope ground squirrel, San Joaquin kit fox, San Joaquin pocket mouse, shorebirds, giant kangaroo rat, Tipton kangaroo rat, Tule elk, and waterfowl. Other than irrigation canals and drainage ditches, the principal

flowing water features in the subarea are the lower Kern River and Poso Creek. The river and creek support an assortment of warm-water fish species including sunfish, catfish, and native nongame fishes.

Recently created habitats in the subarea include: five drainage-water evaporation ponds developed during the past 17 years (covering a total of about 950 acres, about 13 percent of all the evaporation pond acreage in the valley); and an expanding acreage of agroforestry plantations (many planted in the last 2-4 years). The evaporation ponds are heavily used by aquatic birds for wintering and breeding habitat (Barnum, 1989; Hoffman-Floerke, 1985; Schroeder et al., 1988; Tribbey, 1988; Tribbey and Beckingham, 1986). Studies conducted by CSU, Fresno for the SJVDP have revealed that the agroforestry plantations provide perching, nesting, and burrowing habitat for a variety of birds and mammals.

Problems. Contamination field studies have documented elevated concentrations of selenium (an indicator of contamination by subsurface drainage water) in water (greater than 5 ppb) and sediments (greater than 0.5 ppm, dry weight) collected from all four of the sampled evaporation ponds in the Kern Subarea, including: Sam Andrews (aka Rainbow Ranch), Carmel Ranch (aka Willow Creek), Lost Hills Ranch, and Westfarmers (aka Lost Hills) (Westcot et al., 1988a). No water or sediment samples have been collected from Chevron Land Company ponds. Food-chain organisms have been collected from four of the five evaporation ponds in the subarea (no samples have been taken from Chevron Land Company) and chemically analyzed for selenium. Concentrations of selenium toxic to mallards (equal to or greater than 7 ppm, dry weight) have been found in food-chain organisms collected from all four of those ponds (D. A. Barnum and D. S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA

[unpublished data]; S. A. Ford and D. K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]; T. Heyne, CSUF and M. Kie, CDFG, Fresno, CA [unpublished data]; Schroeder et al., 1988; and White et al., 1987). Studies of reproduction and/or survival of aquatic birds have been conducted at two of the subarea's five ponds. Significantly elevated frequencies of adverse biological effects (that are believed to be contaminant-related) have been documented in breeding aquatic birds at one pond, Westfarmers (Ohlendorf, 1988; Skorupa, 1989; Skorupa and Ohlendorf, 1989; and Skorupa and Ohlendorf, 1988).

Water, sediments, and food-chain organisms have been collected from Goose Lake Canal, Poso Creek, and Kern NWR, and samples have been chemically analyzed. Selenium concentrations in samples of water and sediments collected from these areas have not been elevated. With the exception of one sample of mosquitofish collected from Kern NWR, selenium concentrations in samples of food-chain organisms collected from these areas have not exceeded known toxic thresholds (Schroeder et al., 1988). No contaminant-related studies of reproduction or survival of fish or wildlife have been undertaken in any of these areas.

It is currently unknown whether agroforestry plantations in the subarea are contaminated by drainage-water substances of concern such that they pose a contaminant threat to wildlife using the sites.

Apparently no drainage water has been used to help satisfy water needs for public or private wildlife areas in the Kern Subarea. Kern NWR needs 25,000 acre-ft/yr of firm, nontoxic freshwater to satisfy optimum management objectives. At least 13,500-14,500 acre-ft/yr of firm, nontoxic freshwater is needed to satisfy optimum management objectives for private duck clubs in the

subarea. None of these public or private wildlife areas currently has a reliable supply of nontoxic freshwater. Wildlife agencies and interests have determined that the Tulare Basin (including the Westlands, Tulare, and Kern Subareas) is 5,000 acres short of the wetland habitat needed to support international waterfowl population objectives.

Instream fishery flow needs for the Kern River and Poso Creek are unknown.

Objectives. Protection of remaining wildlife habitats and populations in the Kern Subarea will probably require acquisition and management of some lands by wildlife organizations and/or appropriate financial incentives for private landowners to forgo conversion of remaining wetlands (e.g., through acquisition of perpetual wetlands easements). The acquisition and development of new wetlands (complete with adequate, firm supplies of nontoxic freshwater) would likely provide migratory birds and a broad variety of other wetland-dependent wildlife species with additional protection from drainage-water contaminants. Additional, high quality wetland habitat would be expected to preferentially draw some wildlife away from evaporation ponds, thereby reducing the numbers of individuals exposed to drainage-water contaminants and/or decreasing exposure frequencies and/or durations. Consequently, the frequencies and/or severity of contaminant-caused biological effects associated with the ponds and public health risks associated with game birds using the ponds would be expected to be reduced.

Additional biological monitoring and field and laboratory research are needed to fill in data gaps and determine, for example: (1) What the concentrations of drainage contaminants are in water, sediments, and food-chain organisms in all fish and wildlife habitats in the subarea that are or

have been exposed to drainage water, (2) whether adverse biological effects are continuing at evaporation ponds studied to date and/or at ponds which have not yet been studied, (3) whether newly established agroforestry plantations pose drainage-related contaminant threats to wildlife using the sites, and (4) the quantity, quality, and schedule of instream flows needed in the Kern River and Poso Creek to support viable fisheries.

Concerted action is needed to ensure that those drainage-contaminated evaporation ponds in the Kern Subarea at which significantly elevated frequencies of adverse biological effects have been documented are managed to keep wildlife out, operated in a wildlife safe manner, or are decontaminated and closed. No other habitat decontamination and restoration needs have been identified to date in the subarea.

Apparently no subsurface drainage water has been intentionally used to help satisfy water needs for public or private wildlife areas in the subarea; therefore, no substitute water supply objective has been established.

Improvement of wildlife resources in the Kern Subarea would occur if: Kern NWR and Duck Club were provided with an additional firm, nontoxic freshwater supply totaling 25,400 acre-ft/yr, and private duck clubs in the subarea were provided with an additional quantity of firm, nontoxic freshwater greater than 13,500-14,500 acre-ft/yr (these volumes are equal to the additional water needed to satisfy optimum management objectives for existing lands); and/or 5,000 acres of new wetlands and associated water supplies were provided in the subarea.

Available Technologies Alternative

The available technologies alternative for the Kern Subarea for the year 2000 is comprised of three components: (1) Actions to sustain irrigated

agriculture, (2) actions to protect public health, and (3) actions to protect and restore fish and wildlife and their habitats. Each component is discussed and presented in the following sections. The State water-quality objectives for surface water are viewed as constraints that would be met simultaneously with accomplishment of these actions, and the technical analyses have taken this into account--limiting actions that do meet the constraints.

Actions to sustain agriculture. Tables 4-19 through 4-22 present options that have been applied to reduce problem-water volumes in water-quality Zones A, B, C, and D (Figure 4-K8). From examination and comparison of those tables, the following can be concluded about the agricultural component of the alternative:

- Source-control options included in each zone would achieve about 47 percent of the targeted reduction in problem water.
- Drainage-water reuse options also included in each zone would achieve from 33 percent to 47 percent of the targeted reduction in problem-water volume.
- Ground-water management options would be used in conjunction with reuse in Zones B and D. The semiconfined aquifer underlying these zones appears to be moderately suitable for pumping to lower the water table and provide room for deep percolation from the saltbush.
- Existing evaporation ponds would be used in Zones A and D, and new evaporation ponds would be constructed in Zone C (an area of low selenium concentrations in ground water). All ponds would have to be bird-safe or bird-free; the high unit cost reflects that constraint.

Table 4-19

AVAILABLE TECHNOLOGIES ALTERNATIVE
KERN SUBAREA - ZONE A

(Estimated volume of problem water to be managed by year 2000 = 18,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	12,000	660,000	4,800
A-2, A-3	Improve irrigation management	5	12,000	60,000	2,400
A-9	Manage water table to increase evapotranspiration	30	6,000	180,000	1,200
	Drainage-Water Reuse				
D-1	Irrigate saltbush (b)	473	2,100	993,300	6,600
	Drainage-Water Disposal				
E-5	Use existing evaporation ponds (c)	240	800	192,000	3,000
	TOTALS			2,085,300	18,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 1,300 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

Table 4-20

AVAILABLE TECHNOLOGIES ALTERNATIVE
KERN SUBAREA - ZONE B

(Estimated volume of problem water to be managed by year 2000 = 1,500 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	1,000	55,000	400
A-2, A-3	Improve irrigation management	5	1,000	5,000	200
A-9	Manage water table to increase evapotranspiration	30	500	15,000	100
	Drainage-Water Reuse				
D-1	Irrigate saltbush (b)	241	200	48,200	500
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (c)	154	200	30,800	300
	TOTALS			154,000	1,500

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 100 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(c) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

Table 4-21

AVAILABLE TECHNOLOGIES ALTERNATIVE
KERN SUBAREA - ZONE C

(Estimated volume of problem water to be managed by year 2000 = 3,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	2,000	110,000	800
A-2, A-3	Improve irrigation management	5	2,000	10,000	400
A-9	Manage water table to increase evapotranspiration	30	1,000	30,000	200
	Drainage-Water Reuse				
D-1	Irrigate eucalyptus trees (b)	625	200	125,000	1,100
D-1	Irrigate saltbush (c)	241	100	24,100	300
	Drainage-Water Disposal				
E-5	Construct new evaporation ponds (d)	1,205	50	60,250	200
	TOTALS			359,350	3,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.
(b) Includes 100 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.
(c) Includes 100 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.
(d) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

Table 4-22

AVAILABLE TECHNOLOGIES ALTERNATIVE
KERN SUBAREA - ZONE D

(Estimated volume of problem water to be managed by year 2000 = 23,000 acre-feet)

1 Option No. (Chap. 3)	2 Action(s)	3 Annual Cost per Acre ($)	4 Land Area (acres)	5 Total Annual Cost (3)X(4) ($)	6 Drainage Volume Reduction (acre-ft)
	Source Control				
A-1	Improve irrigation methods (a)	55	15,000	825,000	6,000
A-2, A-3	Improve irrigation management	5	15,000	75,000	3,000
A-9	Manage water table to increase evapotranspiration	30	7,500	225,000	1,500
	Drainage-Water Reuse				
D-1	Irrigate saltbush (b)	241	2,600	626,600	8,300
	Ground-Water Management				
B-2, B-3	Pump from semiconfined aquifer (c)	154	2,600	400,400	3,800
	Drainage-Water Disposal				
E-5	Use existing evaporation ponds (d)	240	100	24,000	400
	TOTALS			2,176,000	23,000

(a) Modify irrigation methods from 1/2-mile furrows without a return system to 1/4-mile furrows with a return system.

(b) Includes 1,800 acre-ft reduction in deep percolation, because land is no longer receiving a freshwater supply.

(d) Ground-water pumping to control shallow water levels would be limited to area planted to saltbush.

(e) Cost depends on drainage-water selenium concentrations; cost is directly proportional to concentrations.

Costs of the agricultural component are calculated as follows:

1. Average annual cost of source-control options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$2,250,000}{21,000\ \text{AF}} = \$107/\text{AF}$$

2. Average annual cost of combined reuse, disposal, and ground-water options:

$$\frac{\text{sum of annual costs}}{\text{sum of volumes reduced}} = \frac{\$2,524,650}{24,500\ \text{AF}} = \$103/\text{AF}$$

3. Average annual cost of the agricultural component:

$$\frac{\text{costs }(\$2,250,000 + \$2,524,000)}{\text{volumes }(21,000\ \text{AF} + 24,500\ \text{AF})} = \frac{\$4,774,650}{45,500\ \text{AF}} = \$105/\text{AF of problem water}$$

Costs (\$105/AF) x drainage factor (0.75 AF/acre) = \$79/acre of contributing land

To summarize, the set of actions to sustain irrigated agriculture in the Kern Subarea under this alternative is: (1) Conserve irrigation water through improvements in technology and management, (2) reuse drainage water on eucalyptus trees, (3) drain the eucalyptus trees, (4) reuse the resultant drainage water on saltbush, and (5) dispose of the deep percolation from saltbush by either draining or pumping from beneath the saltbush (storing water with high levels of mineral concentrations in bird-safe evaporation ponds or in the upper part of the semiconfined aquifer).

Actions to minimize public health risks. General actions that could be continued or undertaken to minimize public health risks in the subarea are listed in the "Public Health Component" section located near the beginning of this chapter. Public health warnings are needed for Westfarmers evaporation ponds.

Actions that would protect, restore, and provide substitute water supplies for fish and wildlife resources. Protection of existing wildlife resources in the Kern Subarea could occur through: (1) Protection of

remaining, unprotected wetlands in the subarea through acquisition and management by wildlife organizations or by use of other legal protections (unprotected wetlands in the subarea [i.e., duck club wetlands] currently total approximately 2,500-2,700 acres), (2) provision of a firm, nontoxic freshwater supply to all remaining wetlands-wildlife areas (the freshwater supply deficit for the subarea totals more than 38,000 acre-ft/yr), and/or (3) the acquisition, development, and management of new wetlands (up to 5,000 acres of additional wetlands complete with adequate, firm supplies of nontoxic freshwater [about 20,000 acre-ft/yr] are needed in the Tulare Basin [Westlands, Tulare, and Kern Subareas] to support international waterfowl population objectives). If combined with hazing programs at the ponds, the provision of adequate, firm, nontoxic freshwater supplies for existing wetlands-wildlife areas and/or the purchase and development of new wetlands would reduce some of the ongoing and anticipated adverse effects upon aquatic birds created by some evaporation ponds in the subarea. Drainage-water evaporation ponds in the valley need to be treated as special cases, because although they are not specifically managed as wildlife habitat, they nonetheless experience considerable use by aquatic birds. Due to contamination of some ponds, they can also be lethal, attractive nuisances. Actions that are currently being taken to address this problem include signing of mutual "monitoring and mitigation agreements" between pond owners and the DFG which require hazing at toxic ponds. Additionally, field testing of various techniques to make the ponds bird-safe or bird-free is occurring at selected ponds but could be greatly expanded. A third set of actions that would further reduce adverse effects at the ponds is the development and management of new wetlands habitat in their vicinity.

The provision of adequate, additional volumes of firm, nontoxic freshwater supplies to existing and needed wetlands in the Kern Subarea would go a long way toward addressing drainage-related and other fish and wildlife resource problems. Provision of such waters could help protect existing and increased wildlife populations. The SJVDP has estimated that approximately 200,000 acre-ft/yr of irrigation water currently used on the west side and southern end of the San Joaquin Valley could be conserved through on-farm water conservation, improved drainage management, drainage water reuse, and ground-water pumping. Under the available technologies alternative, some of that conserved water would be reallocated to existing wetlands-wildlife areas in the subarea to satisfy existing needs (38,000 acre-feet/year).

SUMMARY AND EVALUATION

The available technologies alternative was developed to: (1) Reduce to zero or manage a total of 307,500 acre-ft/yr of problem water, the volume expected to occur on the west side of the valley by the year 2000, (2) provide water for drainage-related fish and wildlife needs, and (3) minimize drainage-related public health risks. The options that were assumed to be available technologically and to show promise of being cost-effective (by year 2000) were selected and configured for the particular conditions in the Grasslands, Westlands, Tulare, and Kern Subareas. An alternative was not developed for the Northern Subarea because of its comparatively minor drainage problems and the availability of the San Joaquin River for drainage-water disposal.

Summary

The selected options were applied to: (1) 409,000 acres of irrigated land that are projected to overlie problem water in the year 2000, (2) fish

and wildlife habitats that have been and are likely to be adversely affected by agricultural drainage, and (3) valley sites that pose selenium-related public health risks.

The basic rationale in the development of the available technologies alternative is to minimize the production of drainage water. The alternative involves combinations of (1) irrigation improvements, (2) propagation of eucalyptus trees and saltbush (reusing drainage water and managing the deep percolation from the reuse), (3) discharge to the San Joaquin River, (4) a minor amount of storage of drainage water in the semiconfined ground-water aquifer, and (5) disposal of drainage water in bird-free or bird-safe evaporation ponds. Table 4-23 summarizes the fate of problem water in the four subareas utilizing these five general measures.

A major reduction in drainage-water volume would be accomplished by improving irrigation methods, improving irrigation scheduling and system management, and to the extent possible, using increased amounts of the shallow ground water for plant evapotranspiration needs. Over the four subareas, irrigation improvements would reduce the problem-water volume by 128,800 acre-ft/yr (from 307,500 acre-ft/yr to 178,700 acre-ft/yr).

The actions utilized to manage geographically scattered volumes of the remaining 178,700 acre-ft/yr vary by water-quality zone, depending on the specific quality, relative availability of low-cost disposal sites, environmental considerations, ground-water hydrology, and agricultural practices and economics.

Some 35,000 acre-ft of shallow ground water from specific parts of the Grasslands Subarea would be collected in drains and discharged into the San Joaquin River (volume limited by the interim river water-quality objective of

Table 4-23

SUMMARY OF DRAINAGE VOLUME REDUCTION
AVAILABLE TECHNOLOGIES ALTERNATIVE
(acre-feet)

(Estimated volume of Problem Water to be managed by Year 2000 = 307,500 acre-feet)

SUBAREA	REDUCTION OR DISPOSAL METHOD					TOTAL
	IRRIGATION IMPROVEMENTS	DISCHARGE TO SAN JOAQUIN RIVER	EUCALYPTUS AND SALTBUSH PROPAGATION (REUSE)	GROUNDWATER STORAGE	EVAP POND DISPOSAL	
GRASSLANDS	27,200	35,000	21,900	1,700	200	86,000
WESTLANDS	37,900	0	40,400	5,300	400	84,000
TULARE	42,700	0	41,100	300	7,900	92,000
KERN	21,000	0	16,800	4,100	3,600	45,500
TOTAL	128,800	35,000	120,200 (a)	11,400	12,100	307,500

(a) Includes about 20,000 acre-ft reduction in deep percolation, due to replacement of conventional crops with special crops such as eucalyptus trees (assumes no freshwater supply).

5 ppb dissolved selenium). Most of this drainage originates from zones with very low selenium concentrations and relatively low salinity (TDS) levels. The remaining problem water would then be 143,700 acre-ft.

A large percentage of this remaining problem water would be drained from the shallow ground water and used to grow eucalyptus trees and/or saltbush. Saltbush is a very salt-tolerant crop and could be irrigated directly with any of the drainage waters projected to occur. Where drainage-water quality is less than 10,000 ppm salinity, eucalyptus would be grown. Root zones of the trees would be drained to remove highly saline ground water, which could then be used to grow saltbush. This combined growth of harvestable eucalyptus trees and a forage crop (saltbush) provides removal by evapotranspiration of 120,200 acre-ft/yr (including about 20,000 acre-ft/yr reduction in deep percolation as a result of replacement of conventional crops with special crops such as eucalyptus trees).

The remaining 23,500 acre-ft of water would be disposed of in the semiconfined aquifer (11,400 acre-ft/yr) and in bird-free or bird-safe evaporation ponds (12,100 acre-ft/yr). The semiconfined aquifer would be pumped to allow storage of the deep-percolation water in the area planted in saltbush. The effect of controlled pumping from deep within the semiconfined aquifer would be to draw down salty drainage water and store it in the semiconfined aquifer. The effect of such storage would be degradation of the semiconfined aquifer at an increased rate.

In those areas where natural hydraulic or water-quality conditions are not favorable for pumping from the semiconfined aquifer as a means of lowering shallow ground-water levels, evaporation ponds would be utilized to store the remaining problem water. A total of 3,200 acres of ponds would be required,

including 600 acres of new ponds. This total is less than half the current acreage of ponds in the valley. Measures to protect wildlife from risks associated with evaporation ponds include limiting pond size, hazing, vegetation control, water-depth control, drainage-water separation, and providing alternative habitat. The use of conserved irrigation water on waterfowl habitat areas in the vicinity of contaminated ponds would be expected to increase the effectiveness of hazing programs.

Evaluation

Potential effects of the available technologies alternative are summarized in Table 4-24. Direct environmental effects would include impacts on fish and wildlife and their habitats, water quality, public health, and agricultural lands. Other effects include costs, land-use changes, and impacts on agricultural productivity.

Major direct effects. As shown in Table 4-25, 28,200 acres of cropland would be removed from irrigation and used to grow eucalyptus trees and saltbush irrigated with drainage water. A total of 213,100 acre-ft/yr of existing irrigation water supply would be conserved through measures to reduce deep percolation and through pumping from the semiconfined aquifer. Under this alternative plan, most of the "conserved" water would be used as a substitute for drainage water previously used in wetlands areas, to supplement current water supplies to wildlife areas and to augment Merced River and San Joaquin River flows.

The total net cost of the alternative (calculated on the basis of present worth at 10 percent interest and at project lives of from 20 to 40 years) would be \$29,423,000/year, or \$96/acre-ft/yr of problem water in the year 2000. Distributed over the 409,000 acres of contributing lands, the average

Table 4-24

SUMMARY EVALUATION
AVAILABLE TECHNOLOGIES ALTERNATIVE

GRASSLANDS, WESTLANDS, TULARE, AND KERN SUBAREAS

OPTION NO. (Chap. 3)	*ACTION(S)*	*DIRECT ENVIRONMENTAL EFFECTS OF THIS ALTERNATIVE*	*OTHER EFFECTS/REMARKS*
	Source Control		
A-1	Improve irrigation methods (1/4-mile furrow with return system)	o Reduces the volume but increases salt and contaminant concentrations of drainage water. o Conserves irrigation water. o Increases availability of supplemental water for fish and wildlife uses.	o Increases agricultural production cost by approximately $55/acre. o Increases labor and management skill requirements. o Increases risk of reducing crop yields by underirrigation and salinization of soils. o Reduces the amount of applied water, fertilizers, and pesticides.
A-2, A-3	Improve irrigation management (system management and irrigation scheduling)	o Reduces the volume but increases salt and contaminant concentrations of drainage water. o Conserves irrigation water. o Increases availability of supplemental water for fish and wildlife uses.	o Increases agricultural production cost by approximately $5/acre. o Increases labor and management skill requirements. o Increases risk of reducing crop yields by underirrigation and salinization of soils. o Increases crop yield where underirrigation is presently occurring.
A-9	Manage water table to increase evapotranspiration contribution from shallow ground water	o May reduce the volume and salt load of drainage water. o Unless very carefully managed, may increase salt concentration in root zone. o Crops may accumulate Se to higher than normal levels, where shallow ground water has high Se levels. o Higher ground-water levels may adversely affect irrigated agricultural production on adjacent lands.	o Increases agricultural production cost by approximately $30/acre. o Increases labor and management skill requirements. o Increases risk of reducing crop yields due to flooding root zone during critical plant development periods and salinization of the root zone. o Provides means of regulating drainage discharge and reducing drainage management costs. o Reduces the amount of applied water and fertilizers.
	Drainage-Water Reuse		
D-1	Irrigate eucalyptus trees	o Provides potential increase in wildlife habitat acreage. o May increase toxic risks to wildlife (requires long-term monitoring to identify any trends in contaminant accumulation in wildlife). o Reduces drainage-water volume and salt load. o Large plantations may create undesirable microclimatological changes and contribute to air pollution (aromatic organics).	o Increases technical farm labor requirements. o Economic feasibility requires establishment of suitable market for biomass produced. o Assuming limited market, net cost is approximately $625/acre (includes installed drainage facilities and land costs). o Demonstration studies are necessary to determine technical feasibility. o Reduces irrigated agricultural land area by 12,400 acres.
D-1	Irrigate saltbush	o Provides potential increase in wildlife habitat acreage. o May increase toxic risks to wildlife (requires long-term monitoring to identify any trends in contaminant accumulation in wildlife). o Reduces drainage-water volume and salt load. o Requires research and demonstration studies to determine long-term effect of using saltbush as animal feed.	o Increases technical farm labor requirements. o Requires establishment of suitable market for the biomass produced. o Assuming limited market, net cost is approximately $241-473/acre (includes installed drainage facilities and land costs). o Demonstration studies are necessary to determine technical feasibility. o Reduces irrigated agricultural land area by 15,200 acres.

Table 4-24 (Con't)

SUMMARY EVALUATION
AVAILABLE TECHNOLOGIES ALTERNATIVE

GRASSLANDS, WESTLANDS, TULARE, AND KERN SUBAREAS

OPTION NO. (Chap. 3)	ACTION(S)	DIRECT ENVIRONMENTAL EFFECTS OF THIS ALTERNATIVE	OTHER EFFECTS/REMARKS
	Ground-Water Management		
B-2, B-3	Pump from semiconfined aquifer	o Contributes to continuing degradation of the semiconfined aquifer and reduces its long-term availability for benefical use. o Increases available water supply. o Reduces drainage volume requiring disposal. o Reduces risk of Se-laden drainage adversely affecting fish and wildlife. o Immobilizes Se in the semiconfined aquifer when ground water is removed from Sierran sands.	o The cost of approximately $154/acre of land affected by pumping includes ponds to regulate water pumped during nonirrigation periods. o May require demonstration projects to determine effectiveness in each water-quality zone.
	Drainage-Water Disposal		
E-1	Discharge to San Joaquin River without dilution	o Continues TDS, boron, and Se degradation of the San Joaquin River. o If conveyed through natural channels, would expose fish and wildlife within the grasslands area to Se in the drainage water. o Reduces the current amount of drainage water discharged to the river. o Reduces anadromous fish spawning success by attracting migrants into sloughs in which drainage is discharged.	o Increases the risk of impairing the beneficial uses of the river. o Continues controversy between the current water districts discharging to the river and downstream water users regarding water-quality degradation. o Provides a means of exporting dissolved solids from the drainage problem area.
E-5	Use existing evaporation ponds	o Could increase toxic risk to wildlife if Se concentration in water is more than 3 ppb (CDFG determination). o Provides potential for increased wildlife benefits in areas where Se concentration is less than 3 ppb (CDFG determination). o Requires increased freshwater allocation for management of alternative wildlife habitat.	o Low ($35) and high ($240) cost per acre reflect differences in methods and facilities for, respectively, low-selenium waters and high-selenium waters. o Increases technical labor and consulting services requirements. o Requires research and demonstration efforts to develop economic and technically feasible methods for reducing environmental risks.
E-5	Construct new evaporation ponds	o Could increase toxic risk to wildlife if Se concentration in water should prove to be more than 3 ppb (CDFG determination). o Provides potential for increased wildlife benefits in areas where Se concentration is less than 3 ppb (CDFG determination). o Requires increased freshwater allocation for management of alternative wildlife habitat.	o Increases technical labor and consulting services requirements. o Causes permanent land degradation. o Requires research and demonstration efforts to develop economic and technically feasible methods for reducing environmental risks.
	Fish and Wildlife Measures		
F-12	Reallocation of freshwater supplies (to supplement fish flows, replace contaminated ag. drainage used in wetlands, and augment wetland supplies assoc. with evap. pond hazing)	o Increases San Joaquin River flows above the Merced River during anadromous fish out-migration period. o Increases wetland firm freshwater supplies. o Reduces contaminant concentration in wetland soils. o Reduces overall contaminant effects on wildlife. o Decreases the potential of attracting anadromous fish into deadend channels.	o Requires an equitable means of allocating costs of providing supplemental water for fish and wildlife. o May require a regional institution to ensure an equitable allocation of costs. o Requires coordinated operation of water delivery systems and necessary agreement. o May require additional water conveyance facilities.

Table 4-25

MAJOR DIRECT EFFECTS
AVAILABLE TECHNOLOGIES ALTERNATIVE

SUBAREA	WATER QUALITY ZONE	IRRIGATED LAND AREA REDUCTION (acres)	AGRICULTURAL WATER REQUIREMENT REDUCTION (acre-feet/year)	TOTAL ANNUAL COST ($1,000)	SUPPLEMENTAL FISH & WILDLIFE WATER SUPPLIES (acre-feet/year)
GRASSLANDS	A	3,600	38,400	4,642	
	B	800	5,500	769	
	C	0	0	0	
	Subtotal	4,400	43,900	5,411	149,000 (a)
WESTLANDS	A	2,300	17,700	2,425	
	B	1,900	14,800	1,500	
	C	3,600	27,200	3,760	
	D	800	6,700	955	
	Subtotal	8,600	66,400	8,640	0
TULARE	B	3,100	16,700	2,879	
	C	300	3,000	390	
	D	700	4,900	717	
	E	2,050	13,900	2,342	
	F	3,800	24,400	4,270	
	Subtotal	9,950	62,900	10,598	9,700 (b)
KERN	A	2,100	14,300	2,085	
	B	200	1,600	154	
	C	350	2,400	359	
	D	2,600	21,600	2,176	
	Subtotal	5,250	39,900	4,774	38,000 (b)
TOTAL		28,200	213,100 (c)	29,423	196,700

(a) Includes 20,000 acre-feet of anadromous fish flows down the Merced River and 129,000 acre-feet of substitute wetland-wildlife habitat water supplies.
(b) Alternative habitat water supply associated with hazing of evaporation ponds.
(c) Reduction includes 128,800 acre-feet due to improved irrigation and drainage management practices, 72,900 acre-feet due to reduction in irrigated agricultural lands (used to grow eucalyptus trees and saltbush), and 11,400 acre-feet due to increased ground-water pumping to control shallow water depth.

annual cost per acre would be $72 (not including all costs for installing and operating new on-farm drainage systems; i.e., in addition to the present 135,000 acres).

Effects on the San Joaquin River. The alternative would result in significant reductions in discharges to the river of drainage waters containing high concentrations of selenium. Increased discharges of freshwater stored in wetlands in the Grasslands Subarea would be made during March and April. Also, 20,000 acre-ft of freshwater would be used to improve conditions for upstream-migration of adult salmon in the Merced River during October. The dissolved selenium concentrations in the San Joaquin River (measured at Crows Landing Bridge) would be expected to meet the proposed water-quality objective of 5 ppb.

Evaporation ponds. Only 12,100 acre-ft of drainage water would be disposed of in evaporation ponds, or about 35 percent of the drainage-water volume now being disposed of annually in ponds. About 600 acres of new ponds would be constructed, in water-quality zones where selenium concentrations in drainage water are less than 3 ppb. A total of 2,600 acres of existing ponds would be utilized, and it is assumed that approximately 4,700 acres of existing ponds would be closed.

Criteria, guidelines, and procedures for closures or land-use conversions have not been developed by the SJVDP. The Program, however, has developed cost estimates for disposal of hazardous and designated wastes (SJVDP, 1989b).

Salt balance. This alternative, if implemented, would not equalize salt inflow and salt outflow in the west-side San Joaquin Valley. The net accumulation resulting from a continuation of salt imbalance is estimated to

be approximately 3.3 million tons per year. Most of this salt is stored in the water and soil materials that make up the semiconfined aquifer. Over time, such storage would reduce the use potential of the ground water as salt would migrate downward. The average present annual rate of migration of salt downward is estimated at 0.3 foot of vertical movement--but there are major local differences from this rate.

CHAPTER 5. ACTIVITIES AND SCHEDULE FOR PROGRAM COMPLETION

A substantial amount of what is known about drainage and drainage-related problems in the San Joaquin Valley has been summarized in this report. A wide range of options for managing these problems have been identified and discussed, and preliminary alternatives based on the use of available technologies have been presented for each subarea.

A range of alternatives for the planning subareas are being formulated and evaluated. Opportunities are being provided for the general public, special-interest groups, and governmental agencies to play important roles in this formulation and evaluation process. The SJVDP is very interested in having comments from others, particularly concerning possible management options not included in this report; the planning alternatives presented here and other alternatives that should be considered; and planning assumptions and criteria being utilized. Comments will be solicited and utilized throughout the planning process, which will culminate in the recommendation of subarea plans and/or a comprehensive plan for the west side of the valley, as appropriate.

During the remainder of 1989 and in early 1990, the SJVDP will be completing technical studies and other work that fall into two primary areas: (1) Special studies to provide specific information critical to plan formulation and evaluation, and (2) improving the analytic tools used in evaluating options and planning alternatives.

IMPROVING THE INFORMATION BASE

Developing an adequate information base on drainage and drainage-related conditions and problems in the valley has been one of the SJVDP's major activities. Whether by conducting its own studies or contracting with others to develop or collect information or gather useful information collected by others, the SJVDP has worked to answer these questions:

- What are the sources of selenium and other trace elements?
- How are these trace elements mobilized and transported into the ground water?
- What is the geohydrology of ground water in the study area?
- What is the nature, geographic extent, and severity of contamination by trace elements?
- What effects do these trace elements have on fish and wildlife?
- What levels of exposure are safe for fish and wildlife and what levels pose a risk to them?
- Is there a public health risk?
- Which irrigation and drainage management technologies are appropriate for use in the study area?
- Can treatment technologies be developed to remove contaminants?
- Which laws and institutions influence drainage management?
- What are the existing programs, plans, and organizations for addressing drainage and drainage-related problems?
- Can models be developed to accurately estimate the impacts of alternative actions on natural resources and other public values (e.g., ground water, water quality)?

Most of these questions have now been answered. Work yet to be done before completion of the SJVDP by October 1990 is described in the following sections.

<u>Geohydrology</u>

The SJVDP has funded extensive studies by the USGS on hydrologic and geochemical conditions in the valley. The emphasis of these studies has been upon:

- Determining the distribution (area and depth) of selenium and other toxic and potentially toxic constituents in soil and ground water.
- Describing the regional ground-water flow system and related local ground-water flow in drained fields.
- Assessing the mobility of selenium and other toxic substances in ground water.
- Determining the amount and behavior of selenium and other toxic substances in the San Joaquin River and Delta, as a result of drainage-water disposal.

Much of the planned work on mapping the distribution of selenium and other substances of concern in shallow ground water has been completed. Work continues to identify the distribution of dissolved constituents in ground water in areas that have not been studied in detail. Planned work to quantify changes in the ground-water flow system since 1900 is nearly completed. Also, computer models have been developed that will help predict flow-system behavior in response to possible alternative actions.

The work to be completed within the next year includes:

- Estimation of the soluble selenium now in the soils.

- Classification of the geochemistry of the shallow ground water of the ancestral lake basins in the Tulare and Kern Subareas as a necessary first step in applying options.
- Development of riverflow models of the San Joaquin River for use in evaluating alternatives.
- Completion of ground-water quality analyses for the Grasslands-Westlands area.
- Completion of 3-dimensional ground-water quantity model.
- Studies of selenium accumulation in selected benthic organisms of the San Joaquin River and Delta.

The majority of the information needed to complete this work will be developed by fall 1989, with several months needed to use the information and run the computer models. Some preliminary model runs have been made to estimate, for example, the probable success of pumping from the semiconfined ground-water aquifer to help solve drainage problems.

Public Health

Since the release of the report "Agricultural Drainage Water Contamination in the San Joaquin Valley: A Public Health Perspective" (Klasing and Pilch, 1988), which summarized the known toxicological and human exposure information for selenium, boron, and molybdenum, toxicological profiles and exposure assessments for other substances of concern have been in preparation. The next report, scheduled for release in fall 1989, will provide currently available information for arsenic, nitrates, vanadium, uranium, and mercury. Other elements suspected or known to be elevated in human exposure sources as a result of current drainage-water practices also will be evaluated. Additionally, results from a small survey of arsenic,

boron, and molybdenum concentrations in western San Joaquin Valley soils and crops will be reported and consumption rates will be estimated.

Fish and Wildlife Resources

Since the mid-1980's, a broad range of drainage-related biological studies have been conducted by various agencies and groups. Those studies have attempted to determine, among other things, what effects contaminants dissolved in drainage water have had and may have upon fish and wildlife populations, habitats, and public uses of those resources in the San Joaquin Valley. These studies have been conducted principally by the USFWS, DFG, UC, and CSU. Federal funding has been provided through the USBR and USFWS and State funding through the SWRCB.

As a result of these studies, substantial advances have been made in understanding the:

- Geographic extent, severity, and nature of drainage-related contamination of fish and wildlife populations and their habitats in the San Joaquin Valley, and to a lesser extent in the Sacramento-San Joaquin Delta and San Francisco Bay.
- Effects upon fish and wildlife of drainage-contaminated habitats, especially at Kesterson Reservoir and at other evaporation ponds and wetlands in the valley.
- Toxicity to fish and waterfowl of drainage-water substances of concern including selenium, and to a lesser extent boron and arsenic.
- Potential risks to public health posed by drainage-contaminated wild plants, fish, and wildlife.

Information from these studies has been disseminated broadly and has been (and continues to be) used for a variety of purposes, including:

- o Issuance of warnings to advise the public of potential fish and wildlife-related health hazards.
- o Development of protective water-quality regulations.
- o Improved management of fish and wildlife populations and habitats, including public and private wildlife areas.
- o Definition of habitat decontamination and restoration needs.
- o Guidance for ongoing and proposed toxicity and contamination field research.
- o Formulation and evaluation of alternative plans to solve drainage-related problems.

The USFWS has played a major role in the design and conduct of drainage-related fish and wildlife studies in the valley. Many of the USFWS studies have been directly supported by the SJVDP, while other drainage-related USFWS studies and associated activities are funded with USFWS appropriations.

USFWS activities being conducted for the SJVDP in 1989 and early 1990 are:

- o Completion of chemical analyses of samples collected during contaminant field studies and generated by laboratory toxicity experiments.
- o Completion of articles and reports describing findings from laboratory, field, and other studies and assessments.
- o Completion of ongoing contaminant field studies in the Grasslands area.
- o Continuation of ongoing field studies of contamination and biological effects (e.g., studies of reproductive success and survival of young) at selected evaporation ponds in the valley.

- o Completion of ongoing single-element laboratory toxicity experiments including: (1) Assessment of the effects of selenium in the diet on reproduction and early life stages of raptors, and (2) identification (using clinical and biochemical techniques) of bioindicators of wildlife exposure to contaminants (selenium and boron).
- o Completion of ongoing multiple-element (interactive) laboratory toxicity experiments assessing the effects of arsenic, boron, and selenium on reproduction and early life stages of waterfowl.
- o Completion of ongoing laboratory microcosm experiments investigating food-chain bioaccumulation of selenium (including analyses of chemical speciation, transformation, decomposition, and fate).
- o Completion of photointerpretation, mapping, and digitizing (for entry into the computerized geographic information system) of fish and wildlife habitats in the core of the SJVDP principal study area.
- o Completion of mapping and digitizing of biological sampling sites throughout the valley, historic valley surface hydrology, and ranges of key endangered species.

USFWS activities being conducted in 1989 and 1990 with USFWS appropriations are:

- o Continuation of ongoing field studies into the ecology of evaporation ponds and other wetlands in the Tulare Basin (including the types, numbers, and duration of uses by aquatic migratory birds such as waterfowl, shorebirds, and wading birds, and evaluation of factors attracting birds).
- o Conduct of laboratory studies of the survivability of wildlife (especially waterfowl) disease organisms in drainage water.

- Continuation of laboratory toxicity studies of the effects upon chinook salmon in synthetic San Joaquin River water of multiple trace elements in drainage water (e.g., arsenic, boron, molybdenum, selenium, and possibly copper and zinc).

On the basis of this work, the SJVDP will publish in 1989 and 1990 several reports on fish and wildlife resources, including:

- A comprehensive technical report on the work completed to date.
- A report on techniques for restoring habitat contaminated by drainage water.
- A report describing findings of field studies of wildlife use of agroforestry plantations.
- A report on the economic values of wildlife using agroforestry plantations.

Treatment Technology

The SJVDP has conducted an investigative program to identify treatment processes which could remove salts and selenium from drainage water. This program has been conducted under the guidance of the ITAC Treatment Subcommittee, which has advised on the direction of technical study.

The first step in the program involved review of existing technologies, and it was found that there was no proven technology sufficiently advanced for application in the valley. The SJVDP gathered information resulting from ongoing research of the most promising technologies and, in addition, funded laboratory research on several other potentially promising processes.

The field of promising options has been narrowed to: (1) Anaerobic-bacterial treatment, (2) chemical treatment (ferrous hydroxide), (3) microalgal-bacterial treatment, and (4) selenium volatilization in evaporation ponds. A number of research projects on drainage-water treatment

are being completed in the fall of 1989. The results of these projects are now being assessed for the relevancy of the various treatment processes in contributing to solution of drainage problems.

- <u>Anaerobic-bacterial treatment</u>. UC Davis has examined the theoretical aspects of anaerobic-bacterial treatment. Binnie California studied the anaerobic-bacterial process in a minipilot plant operated at Murrieta Farms--with some successes--and completed a report for DWR in 1987. Westlands Water District has delayed a final decision on a large pilot treatment plant pending successful operation of a pilot plant, and the ITAC has recommended funding of a small pilot plant, if necessary. This recommendation is under consideration by the SJVDP.

- <u>Chemical treatment (ferrous hydroxide)</u>. Laboratory studies of this process were completed in early 1987 and appeared to have some promise; however, field batch reactor studies at Murrieta Farms ran into problems because of high nitrates (500-600 ppm) in the drainage water in that area. Treatment of this high-nitrate water took much longer and cost more than laboratory studies had suggested. Most of the drainage water in the Program study area, however, ranges from 5 to 50 ppm nitrates, so further work on this process may be justified. The SJVDP has funded studies designed to reduce the impacts of nitrogen, oxygen, and bicarbonates on the cost of the process.

- <u>Microalgal-bacterial treatment</u>. High-nitrate drainage water also caused interference with selenium removal in field studies by UC Berkeley using algal ponds at Murrieta Farms. The SJVDP has funded laboratory studies and operation of a minipilot plant near

Mendota to collect the information needed before a pilot prototype plant could be built.

- Selenium volatilization (onsite). This process attempts to speed up natural processes which convert selenium into a gas that is released into the air. Major field studies of application of this process to soils are being funded by the USBR as part of its Kesterson Program, while the SJVDP has funded a study of selenium volatilization from water in evaporation ponds.

Institutional Studies

As detailed plans for solving drainage and related problems are developed, questions about institutional constraints and opportunities--laws, regulations, and policies--become increasingly important. The SJVDP has recently initiated a series of institutional studies, including:

- Preparation of an overview of Federal and State regulations, policies, laws, or institutional practices which could affect plans being evaluated.
- Development of a list of key constraints which must be overcome to remove obstacles or take advantage of opportunities related to the plans. (The analysis will also identify ways and likelihood of overcoming these constraints).
- Analysis of alternative formulas for distributing drainage management costs among individual growers, districts, and the Federal and State governments.
- Analysis of the legal authorities required by local districts for effective management of drainage problems.

Social Analysis

SJVDP studies of social factors affecting and affected by drainage and related problems are designed to: (1) Identify how these problems affect different parts of the community, (2) estimate how local organizations and groups will react or contribute to proposed plans, and (3) estimate the impact of proposed plans upon local communities. Studies are currently being conducted in the following areas:

- History and characteristics of agricultural operations. The major work to date is presented in a report on the history of agriculture in the valley, including information such as land ownership patterns, the structure of farm operations, cropping patterns, agricultural employment, and farm worker characteristics. This information is being updated and additional information is being collected.
- Drainage-water management. Reports are being prepared on the role of local water utilities involved in agricultural irrigation and drainage-water management. These reports describe the history, current organization and resources, and interorganizational relationships among drainage-water management organizations. A report on one subarea is complete, and work is continuing on the four other subareas.
- Profile of special-interest groups. This analysis is being done to identify and characterize the key groups and organizations in the study area, with particular attention to their values and attitudes about drainage management alternatives. The profile will include a description of the role these groups have played in identifying drainage issues and in setting the research and policy agenda

concerning drainage-water management, as well as the roles they may play in implementing plans.

IMPROVING EVALUATIVE TOOLS

The study area is sufficiently large and diverse that making estimates of hydrologic and economic changes and trends can be very difficult. To aid in making these estimates, the SJVDP has developed the computerized Westside Agricultural Drainage Economics (WADE) model. The model covers the principal study area and defines relationships between economic, ground-water and salinity, and agricultural production parameters. It will be used to help estimate the effects of one parameter on another in individual alternative plans.

Some related detailed hydrologic and economic studies are being conducted to improve understanding of the relationship between economic and hydrologic processes in the study area and to assess the reliability of WADE model projections. These studies either: (1) Improve the existing economic data base for use in analysis, (2) provide algorithms that improve the manner in which WADE and other models simulate existing conditions, or (3) provide output verification used to check for consistency of results and to assist in calibration of WADE and other models. Brief summaries of the detailed studies follow.

- <u>On-farm drainage flow and quality monitoring</u>. To obtain detailed farm-level data for incorporation in the WADE model, the SJVDP supported expansion of an existing data collection program at Broadview Water District. The additional work included an economic analysis of grower management decisions affecting crop yields and soil salinity and development of crop-specific agricultural

production functions. The relationships among flows, loads, and concentrations of total salts, selenium, and boron in subsurface drainage water were also examined. Results of this study are being used in calibrating the WADE model.

- Survey of water deliveries and consumptive use in the study area. A crop water use survey conducted by the USGS for the SJVDP provided water-use data for both the WADE and USGS ground-water flow models. Current research by the USDA Water Management Lab and monitoring programs by individual water districts provide information on the relationship between water application and ground-water recharge. Irrigation-performance data collected from over 1,000 locations throughout the study area have been placed in the WADE model data bank and will be used in further refining ground-water recharge estimates.
- Potential use of ground-water pumping for water-table management. Field studies conducted west of Firebaugh in the Panoche Water District have demonstrated the technical feasibility of water-table management through pumping. Use of this information in long-term simulation of ground-water pumping strategies will help in evaluating the feasibility, cost, and environmental acceptability of this technology as a component of an overall plan for salt and selenium management.
- Seepage losses from on-farm distribution systems. A study has been completed on estimating seepage losses within Westlands Water District from on-farm distribution systems and on evaluating the net benefits of constructing alternative conveyance systems. Study results have shown that seepage losses are a very small component of

overall recharge to the ground water and that improving irrigation efficiency and distribution uniformity may be a more cost-effective means of reducing drainage flows on-farm.

- Surface-water network model for the Grasslands drainage basin. A surface-water flow and quality model has been constructed by the SJVDP to help in evaluation of various wetland management options, including conjunctive use of drainage water in the Grasslands drainage basin. The model will be used to evaluate management options by showing the effects on monthly return flows to the San Joaquin River from differing land uses in the Grasslands basin. This model can be used with the SWRCB's San Joaquin River model to examine the effects of various management options on salt and selenium loading at various river locations.
- Evaluation of water-table management techniques using controlled drainage systems. The SJVDP has supported development of an irrigation/drainage model that can evaluate the effects of various water-table management strategies on drainage flows and on the rate of salinity buildup in the root zone. It has been calibrated for general use in the study area by intensive field water-table monitoring. The model is being used to obtain more-accurate estimates of seasonal deep percolation losses and upward flow into the root zone from the shallow ground-water table than can be obtained from the WADE model.

PLANNING ACTIVITIES AND SCHEDULE

The ongoing work to improve the information base and analytic tools is being done in support of formulation and evaluation of alternative plans to

solve drainage and drainage-related problems. The major activities and milestones leading to completion and recommendation of plans are:

- o In fall 1989, a series of public meetings will be held to review the options and preliminary alternatives presented in this report and to discuss possible additional alternatives.
- o The alternatives presented in this report will be revised as needed and additional alternatives developed for each subarea.
- o Each alternative plan will be evaluated to determine: (1) Its effectiveness in solving drainage and drainage-related problems, (2) the economic, social, and environmental impacts associated with plan implementation, (3) actions to avoid or minimize negative impacts, and (4) mechanisms and costs for implementation.
- o A comparison will be made between the effects associated with individual plans and the effects of the "future-without" alternative.
- o Alternative plans will be presented in a draft report in mid-1990.
- o A broad public review will be requested of the plans presented in the draft report.
- o The plans will be revised as needed and presented in a final report by October 1990.

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ABBREVIATIONS

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Acre-ft: Acre-feet

As: Arsenic

B: Boron

CDFA: California Department of Food and Agriculture

CDFG: California Department of Fish and Game

CDHS: California Department of Health Services

CDWR: California Department of Water Resources

CFR: Code of Federal Regulations

Cr: Chromium

Cr^{+6}: Hexavalent chromium

CSU: California State University

CSUF: California State University, Fresno

CSWRCB: California State Water Resources Control Board

CVP: Central Valley Project

CVRWQCB: California Central Valley Regional Water Quality Control Board

D-1485: California State Water Resources Control Board Decision 1485

DFG: California Department of Fish and Game

DMC: Delta-Mendota Canal

DWR: California Department of Water Resources

EC: Electrical conductivity

EPA: U.S. Environmental Protection Agency

EPOC AG: EPOC Agricultural Corporation

ET: Evapotranspiration

gal/d: Gallons per day

gal/min: Gallons per minute

GWD: Grassland Water District

HEM: Hydrologic Economic Model

IDP: San Joaquin Valley Interagency Drainage Program (1975-1978)

ITAC: San Joaquin Valley Drainage Program Interagency Technical Advisory Committee

kWh: Kilowatthour

LBL: Lawrence Berkeley Laboratory

Mgal/d: Million gallons per day

Mo: Molybdenum

MW: Megawatt

NFCRC: USFWS National Fisheries Contaminant Research Center

NO_3: Nitrate

NAS/NRC: National Academy of Sciences/National Research Council

NWR: National Wildlife Refuge

O&M: Operation and maintenance

ppb: Parts per billion

ppm: Parts per million

PWRC: USFWS Patuxent Wildlife Research Center

RO: Reverse osmosis

Se: Selenium

SJVDP: San Joaquin Valley Drainage Program (1984-1990)

SLNWR: USFWS San Luis National Wildlife Refuge

SWP: State Water Project

SWRCB: California State Water Resources Control Board

TDS: Total dissolved solids

UC: University of California

UCD: University of California, Davis

URS: URS Corporation

USBC: U.S. Bureau of the Census

USBR: U.S. Bureau of Reclamation

U.S.C.: United States Code

USDA: U.S. Department of Agriculture

USFWS: U.S. Fish and Wildlife Service

USGS: U.S. Geological Survey

WA: California wildlife area

WADE: Westside Agricultural Drainage Economics

GLOSSARY

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Acre-foot: The quantity of water required to cover 1 acre to a depth of 1 foot: equal to 325,851 gallons or 43,560 cubic feet.

Adsorption: The surface retention of solid, liquid, gas molecules, ions, or atoms by a solid or liquid.

Aerobic: Referring to a condition requiring the presence of oxygen. Aerobic bacteria require free oxygen for the metabolic breakdown of materials.

Agroforestry: As used in this report, it is the practice of growing certain types of trees with drainage water. The trees act to dispose of applied drainage and shallow ground water through foliar evapotranspiration and at the same time produce a marketable commodity.

Alluvium: A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water.

Alluvial fan: A low, outspread, relatively flat to gently sloping mass of stream deposits, shaped like an open fan or a segment of a cone deposited by a stream, especially in a semiarid region at the place where it issues from a narrow mountain valley upon a plain or broad valley.

Anadromous fish: An ocean-going fish which breeds in freshwater.

Anaerobic: Referring to the condition of existing in the absence of oxygen. Anaerobic bacteria can survive in the partial or complete absence of air.

Aquifer: An underground geologic formation that stores and transmits water and yields significant quantities of water to wells and springs.

Attenuation: In the context of this report, it refers to the reduction of the amount of metal species transmitted through a soil column. Research has been conducted on the attenuation of selenium.

Basin trough: A depressed, sediment-filled area at the center of the valley containing a long narrow depression in the earth's surface.

Bioaccumulation: The uptake and accumulation of a chemical by plants and animals directly from the environment (i.e., from water, sediment, soil, or air) or through the diet. See **Bioconcentration** and **Biomagnification**.

Bioconcentration: The uptake and accumulation of a chemical by plants and animals directly from the environment, resulting in greater whole-body concentrations than those found in the environment. See **Bioaccumulation** and **Biomagnification**.

Biomagnification: The uptake and accumulation of a chemical by plants and animals through their diet, resulting in whole-body concentrations that increase at successively higher trophic levels of the food chain. See **Bioaccumulation** and **Bioconcentration**.

Compensation: Something given or received as an equivalent or as reparation for a loss, service, or debt.

Confined aquifer: An aquifer bounded above and below by impermeable beds or beds of distinctly lower permeability than the aquifer itself.

Conjunctive use: A resource utilization or management plan in which surface- and ground-water supplies are used in a manner to maximize use from both without degradation to either.

Contamination: The addition to a given medium, such as water, of detrimental substances which adversely affects its use.

Crop consumptive use: The use of water by crops in which the water is lost from the soil-plant system by evapotranspiration.

D-1485: The August 1978 California State Water Resources Control Board "Decision in Furtherance of Jurisdiction Reserved in Permits of United States Bureau of Reclamation for the Federal Central Valley Project and Department of Water Resources for the State Water Project."

Deep percolation: The downward percolation of water past the lower limit of the root zone of plants, usually greater than 5 feet below the surface of the ground.

Delta: A low, nearly flat alluvial tract of land formed by deposits at or near the mouth of a river. In this report, Delta usually refers to the delta formed by the Sacramento and San Joaquin Rivers.

Distribution uniformity: A measure of how evenly water soaks into the ground across a field during irrigation.

Drainage problem area: A land area characterized by a condition of waterlogging and related water-quality problems. Includes land areas now drained or land areas that likely will require drainage.

Drainage water: Surplus water removed from within the soil by natural or artificial means such as by drains placed below the surface to lower the water table below the root zone. In this report, drainage water refers to subsurface drainage water, unless otherwise qualified.

Drained area: Agricultural lands on which the shallow ground-water level is controlled either by on-farm (tile) drains installed at a 6- to 10-foot depth or by pumping from the semiconfined aquifer.

Dry year: In this report, a dry water year is defined to be (and consistent with DWR Bulletin 120) when estimated unimpaired runoff to the San Joaquin River and key tributaries is between 3,370,000 and 4,130,000 acre-feet, except in years following a critical year, when dry is between 4,130,000 and 5,320,000 acre-feet.

Endangered species: Any species or subspecies of bird, mammal, fish, amphibian, reptile, or plant which is in serious danger of becoming extinct throughout all or a significant portion of its range.

Electrical conductivity (EC): The ability of a particular parcel of water to conduct electricity. The EC of a water sample is an indirect measure of the total dissolved solids (TDS) or salinity of a water sample. Units of reporting are siemens, which are equivalent to the older unit "mhos". Microsiemens per centimeter is abbreviated as uS/cm.

Evaporation: The change of a substance from the solid or liquid phase to the gaseous or vapor phase.

Evaporative concentration: Process of increasing the concentration of dissolved salts or other substances through evaporation.

Evapotranspiration: Water lost as vapor from a given area of soil through the combined processes of evaporation from soil surface and transpiration from plants.

Facultative bacteria: Microorganisms capable of adaptive response to varying environments (e.g., adaptive to aerobic or anaerobic conditions).

Fallow: Land that is tilled but left unseeded during the growing season.

Field capacity: The capacity of a field to hold moisture, measured as the ratio of water retained by the soil to the weight of the dry soil.

Furrow: A long, narrow, shallow trench made in the ground by a plow or other implement.

General study area: The entire San Joaquin Valley from the drainage divide of the Coast Ranges to the foothills (1,000-foot elevation) of the Sierra Nevada.

Hazardous waste: Chemical waste from processes consisting of materials that may be toxic, corrosive, flammable, explosive, or radioactive which can endanger living organisms, especially human health, if handled improperly.

Haze: As used in this report, it means the harassment of birds with noise and other agitation to force them to leave an area which has been evaluated as hazardous to their survival.

Heavy metal: Metal elements having a molecular weight greater than that of sodium (23) or having a specific gravity of 5 or more. Heavy metals are often toxic to living organisms at low concentrations and tend to accumulate in the food chain.

Hydraulic connections: The situation existing between two aquifers whereby the openings allow water to go from one aquifer to the other.

Hydrologic budget: An accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project. Synonyms are: water budget, water balance, and hydrologic balance.

Immobilization: In the context of this report, it is the application of processes and procedures to retain toxic elements, especially selenium, in a given (soil) area. This is done to limit the movement and availability of those metal species which may make them environmental hazards.

Improvement: For purposes of the SJVDP, improvement of fish and wildlife resources means increases in habitats or populations beyond protection, restoration, and substitute water-supply levels.

Infiltration: The flow of a fluid into a substance through pores or small openings. It connotes flow into substances as opposed to percolation, connoting flow through a porous substance.

Infiltration rate: A measure of how fast water soaks in when it is placed on a soil surface.

In situ: In the original location or place.

Ion exchange: A reversible chemical reaction between a solid (ion exchanger) and a fluid (usually a water solution) by means of which ions may be interchanged from one substance to another.

Irrigable area: Agricultural lands which can be irrigated with available water supplies.

Irrigation efficiency: Irrigation application efficiency is the ratio of the average depth of water infiltrated and stored in the root zone to the average depth of water applied to the field. An estimate of the application efficiency of an irrigation system is obtained by dividing the crop water use between irrigations by the amount of water applied during the last irrigation.

Lateral flow: Generalized direction of waterflow at right angles to the vertical.

Leaching: The dissolution and flushing of salts from the soils by the downward percolation of water.

Methylation: The chemical attachment of one or more methyl (CH_3) groups to an element or compound.

Migratory birds: Birds which move from one habitat to another. For legal purposes, migratory birds include those series listed in 50 CFR 10-13.

Mitigation: One or all of the following: (a) Avoiding an impact altogether by not taking a certain action or parts of an action, (b) minimizing impacts by limiting the degree or magnitude of an action and its implementation, (c) rectifying an impact by repairing, rehabilitating, or restoring the affected environment, (d) reducing or eliminating an impact over time by preservation and maintenance operations during the life of an action, and (e) compensating for an impact by replacing or providing substitute resources or environments.

Mobilization: In the context of this report, it is the various processes, natural or man-caused, which tend to "mobilize" or make available to movement, especially in water, various metallic species, particularly selenium. With mobilization, they may become environmental hazards.

Oxidant: A chemical species losing electrons in a reaction, increasing the positiveness of its valence.

Oxidation: A chemical reaction taking place by loss of electrons or addition of oxygen.

Oxidation state: In chemical terms, it is the number of electrons that can be added or subtracted from a chemical atom in a combined state in order to convert it to elemental form. Also known as the oxidation number or valence and could be positive or negative.

Part per billion (ppb): One part by weight per 1 billion (10^9) parts. In water, nearly equivalent to 1 microgram per liter (ug/L), or 1 microgram per kilogram (ug/kg) in solids.

Part per million (ppm): One part by weight per 1 million (10^6) parts. In water, nearly equivalent to 1 milligram per liter (mg/L), or 1 milligram per kilogram (mg/kg), also 1 microgram per gram (ug/g).

Percolation: The downward movement of water through the soil or alluvium to the ground-water table.

Piezometric head: The level to which water from a confined aquifer will rise in a well under static (nonpumping) conditions.

Potential problem water: Shallow ground water within 5 feet of the surface of irrigated lands during at least part of the year, and which generally has chemical characteristics that adversely affect agriculture--and if the water were to be drained--fish and wildlife, public health, or attainment of State surface-water quality objectives.

Preirrigation: Application of irrigation water prior to planting in order to increase the soil moisture content to its maximum field capacity.

Pressure surface: See Piezometric head.

Principal study area: Primarily the west side of the San Joaquin Valley comprising those lands, waters, and related resources that are currently affected by problems related to agricultural drainage, as well as lands likely to be affected in the future.

Problem water: That part of potential problem water that is either (1) drained, or (2) stored in the semiconfined aquifer through the influence of deep-well pumping that lowers the shallow water table.

Program: Used alone, refers to the San Joaquin Valley Drainage Program.

Program study area: Generally the term is synonymous with the principal study area. The shortened term "study area" is also used.

Recharge: The processes involved in the absorption and addition of water to the zone of saturation, which is the subsurface zone filled with water under pressure greater than that of the atmosphere.

Reclamation: The act or process of reclaiming: as reformation, rehabilitation, restoration to use, recovery.

Recruitment: As used in fish and wildlife discussions, it is the survival of juveniles to adult stage (e.g., survival of chicks to flight).

Redox potential: A numerical index of the intensity of oxidizing or reducing conditions within an aqueous system. The redox potential, Eh, is given in volts, positive values indicating relatively oxidizing conditions and negative values indicating relatively reducing conditions.

Redox system: A chemical system in which reduction and oxidation reactions take place; a shortened form for "reduction-oxidation system."

Reduced egg hatchability: Reduction in the percentage of full-term eggs that hatch, compared with the percentage that would be expected in wild, uncontaminated populations of the same species.

Reductant: A chemical species receiving electrons in a reaction, decreasing the positiveness of its valence.

Reduction: A chemical reaction taking place by acceptance of electrons, removal of oxygen, or addition of hydrogen.

Replacement water: See Substitute water supply.

Reproductive failure: As used in fish and wildlife discussions, means extremely low or no recruitment.

Riparian: Pertaining to the banks and other terrestrial environs adjacent to water bodies, watercourses, and surface-emergent aquifers (e.g., springs, seeps, and oases), whose waters provide soil moisture significantly in excess of that otherwise available through local precipitation. Vegetation typical of this environment is dependent on the availability of excess water.

Root-zone storage: Water present in the first few feet, usually within 5 feet below the surface of the ground, in field crops and vegetables; within 10 feet with some fruit and nut trees.

Salinity: The salt content of dissolved mineral salts in water or soil. Salinity in water is measured by determining the amount of total dissolved solids (TDS) or by the electrical conductivity (EC); 1000 uS/cm is approximately equal to 650 ppm as TDS.

Salts: In chemistry, the compound formed when the hydrogen of an acid is replaced by a metal or its equivalent. Examples are sodium chloride, calcium sulfate, magnesium carbonate, etc. In this report, it generally refers to chemical salts as they are dissolved in water or present in soils. The major components of drainage water salts are sodium, sulfate, and chloride.

Salt balance: Refers to the equilibrium established between salts imported to an area and the salts exported from the same area. When used in a regional sense, imported salts are those contained in surface-applied water and may include other inputs such as fertilizer, soil amendments, and precipitation; exported salts are those conveyed from the area through surface and subsurface flows. The term "salt balance" can also be applied to the crop root zone. In this sense, it refers to an equilibrium state of soil salinity where there is no net salt accumulation in the root zone. Net accumulation of salt in the crop root zone can cause a reduction in crop yields.

Salt load: Refers to the total amount of salts contained in a given volume of water entering or leaving an area.

Seepage: Water escaping from a channel or impoundment by percolation.

Selenate: Ionized selenium, usually present as a salt, existing in a valence (or oxidation) state of +6. The chemical symbol is SeO_4^{-2}.

Selenite: Ionized selenium, usually present as a salt, existing in a valence (or oxidation) state of +4. The chemical symbol is SeO_3^{-2}.

Semiconfined aquifer: As used in this report, it includes all aquifers above the Corcoran Clay, including the so-called unconfined aquifer.

Shallow ground water: Ground water within 20 feet of the land surface.

Sierran sand: A term referring to a distinct subsurface body of water-bearing material underlying the San Joaquin Valley. These deposits originated from the Sierra Nevada. Term is equivalent to "Sierran sediment" and "Sierra Nevada sediment."

Soil salinization: The accumulation of soluble salts by the evaporation of the waters that bore them to the soil zone.

Solar ponds: Nonconvective, salt-gradient solar ponds discussed in this report are about 6.5 to 16.5 feet deep with three distinct water salinity/density zones. Short-wave solar radiation penetrates the upper zones into the lower, more dense, heat storage zone and raises its temperature. The stored heat can be used as a low-temperature energy source.

Specific yield: The specific yield, S_y, of a soil is the ratio of the volume of water that, after saturation, can be drained by gravity, to its own volume. $S_y = w_y/V$ where w_y is the volume of water drained and V is the bulk volume of soil.

Subsidence: A local mass movement that involves principally the gradual downward settling or sinking of the earth's surface with little or no horizontal motion. It may be due to natural geologic processes or mass activity such as removal of subsurface solids, liquids, or gases, and wetting of some types of moisture-deficient loose or porous deposits.

Substances of concern: One of a group of toxic or potentially toxic chemical elements or constituents present in agricultural drainage water.

Substitute water supply: An adequate, nontoxic, and reliable freshwater supply equal in volume to the agricultural drainage water previously used by wildlife and/or wildlife habitat. In practical application, it is water to replace a supply on which biological dependency has developed.

Subsurface drain: Perforated pipe generally installed 4 to 10 feet below the land surface to intercept and convey excess water away from the crop root zone by gravity.

Subsurface drainage: See **Drainage water**.

Sump: A basin, pool, or ponding site into which unwanted or contaminated material can be placed until removed for disposal.

Tailwater: Irrigation water which flows over an irrigated field without infiltrating the soil. Synonymous with "surface drainage water" and "irrigation return flow."

Tile drain: An on-farm subsurface drain made of flexible plastic pipe (formerly made of clay tile).

Tillage: Preparation or cultivation of land for growing crops.

Total dissolved solids: A measure of the amount of dissolved material in a liquid (usually water). It is used to determine salinity. The procedure requires measuring (weighing) the amount of solid remaining after evaporation of the liquid for a given time period and at a specified temperature.

Trace elements: Those elements present in the environment at small but measurable concentrations, usually less than 1 part per million.

Transpiration: The passage of a gas or liquid (in the form of vapor) through a membrane or other tissue.

Trophic level: Any of the feeding levels through which the passage of energy through an ecosystem proceeds; examples are photosynthetic plants, herbivorous animals, and microorganisms of decay.

Unconfined aquifer: An aquifer containing ground water that has a free water table; i.e., water not confined under pressure beneath relatively impermeable rocks.

Upflux: The ground-water contribution to evapotranspiration through the process of upward capillary flow. Sometimes called "upward flow" or "upward flux."

Upland: A land zone sufficiently above and/or away from freshwater bodies, watercourses, and surface-emergent aquifers to be largely dependent on precipitation for its water supplies. As used in this report, means lands other than those which are seasonally or permanently wet; i.e., as a wetland.

Valence: See **Oxidation state**.

Vernal pool: A habitat covered by shallow water for extended periods during the cool season but completely dry for most of the warm season.

Volatilization: The conversion of a chemical substance from liquid or a solid state to a gaseous or vapor state.

Waste stream: The aqueous effluent from a treatment process or other chemical process system that contains waste substances, such as sewage or chemicals, which can be toxic or polluting and could become an environmental threat if not disposed of or treated properly.

Water budget: See **Hydrologic budget**.

Waterlogged: Soaked or saturated, said of an area that is affected by a high water table; i.e., where water stands near, at, or above the land surface.

Water table: The area in unconfined subsurface material where hydrostatic pressure equals atmospheric pressure. Generally, the boundary between the saturated and unsaturated subsurface soil zones.

West-side San Joaquin: Meaning the west side of the San Joaquin Valley. Generally, used as a synonym for the principal study area.

Wetland: A zone periodically or continuously submerged or having high solid moisture, which has aquatic and/or riparian vegetation components and is maintained by water supplies significantly in excess of those otherwise available through local precipitation.

Wildlife habitat: An area that provides a water supply and vegetative habitat for wildlife.